Changes in abundance of deep water amphipod *Diporeia* (Pontoporeiidae) in eastern North American lakes with or without *Dreissena* mussels.

R. Dermott, R. Bonnell, and P. Jarvis

Great Lakes Laboratory for Fisheries and Aquatic Sciences
867 Lakeshore Road
Burlington, Ontario L7R 4A6

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R. Dermott, R. Bonnell, and P. Jarvis

Great Lakes Laboratory for Fisheries and Aquatic Sciences
Bayfield Institute
Fisheries and Oceans Canada
867 Lakeshore Road
Burlington, Ontario
L7R 4A6

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ABSTRACT

Dermott, R., Bonnell, R., and Jarvis, P. 2006. Changes in abundance of deep water amphipod *Diporeia* (Pontoporeiidae) in eastern North American lakes with or without *Dreissena* mussels.

Dramatic declines of the amphipod *Diporeia* (Pontoporeiidae) occurred in the Great Lakes after the arrival of *Dreissena* in the early 1990s. To investigate if declines were occurring elsewhere, densities in 2001 – 2003 were compared to historical data from 14 smaller regional lakes in Quebec, New York State, Ontario, and Manitoba. In four of the lakes, density of other invertebrates was also examined to determine if there were historical trends in other taxa. Of the five lakes that had *Dreissena*; only Lake Champlain yielded no *Diporeia*, densities in South Bay (Georgian Bay) decreased, yet in Cayuga and Seneca Lakes where *Dreissena polymorpha* or *D. bugensis* have been abundant for 10 years, *Diporeia* still remained plentiful. Seven of the nine lakes classified as lakes without mussels, including eutrophic Lake Winnipeg, maintained abundant populations of *Diporeia*, the remaining two lakes had densities lower than historical values. There was no evidence of a regional decrease, however statistically the presence of *Dreissena* reduced *Diporeia* populations in the data set examined.

RÉSUMÉ

Dermott, R., Bonnell, R., and Jarvis, P. 2006. Changements dans l'abondance des amphipodes *Diporeia* (Pontoporeiidae) d'eau profonde dans les lacs de la partie est de l'Amérique du Nord pourvus ou dépourvus de moules *Dreissena*.

On a observé des baisses spectaculaires des amphipodes *Diporeia* (Pontoporeiidae) dans les Grands Lacs après l'arrivée des moules *Dreissena* au début des années 1990. Pour déterminer si des baisses se produisaient ailleurs, on a comparé les densités en 2001 - 2003 aux données historiques provenant de 14 lacs régionaux plus petits du Québec, de l'État de New York, de l'Ontario, et du Manitoba. Dans 4 des lacs, on a également examiné la densité d'autres invertébrés afin de déterminer s'il y avait des tendances historiques dans d'autres taxums. Parmi les 5 lacs où se trouvent les moules *Dreissena,* seul le lac Champlain n'a produit aucun amphipode *Diporeia* et les densités dans la baie Sud (baie Georgienne) ont diminué; toutefois, dans les lacs Cayuga et Seneca où les moules *Dreissena polymorpha* ou *D. bugensis* ont été abondantes pendant 10 ans, les amphipodes *Diporeia* sont quand même demeurés abondants. Sept des 9 lacs classés comme des lacs dépourvus de moules, y compris le lac Winnipeg eutrophe, ont conservé d'abondantes populations d'amphipodes *Diporeia*; les 2 autres lacs avaient des densités inférieures aux valeurs historiques. Il n'y avait aucun signe d'une diminution régionale; cependant, statistiquement, la présence des moules *Dreissena* a réduit les populations d'amphipodes *Diporeia* dans les ensembles de données examinés.

INTRODUCTION

Benthic communities have historically sought out a balance within their environment. 10,000 years ago Toiga, the last of the Wisconsinian group of continental glaciers, trapped *Diporeia* in the newly formed the Great Lakes (Harris et al. 2003). The ancestors of present day *Diporeia* not only survived in these deep coldwater lakes but multiplied to such a degree that in 1985 authors Ryder and Edwards proposed that for the oligotrophic/mesotrophic portion of a given body of water where *Diporeia* existed, one could successfully use their density as a measurement of that ecosystem's health (Koonce 1995). Thirteen years later after the Ryder and Edwards proposal, in preparation for the 1998 State of the Lakes Ecosystem Conference (SOLEC), Bertram and Stadler-Salt (1999) recognised the historical dominance of *Diporeia* in cold, deepwater habitats as basis for evaluating ecosystem health resulting in this amphipod being assigned SOLEC Indicator #123. The irony was at the time of this conference *Diporeia* populations were being seriously jeopardized in North America due to their unexplained absence from sediments they had steadfastly populated for thousands of years. It has become clear that current events such as increased eutrophication, the arrival of introduced species, and climatic variability are capable of altering the structure of benthic communities and change the taxa present, including the "benthic thermometer" itself.

The amphipod *Diporeia* spp., formerly *Pontoporeia affinis*, was often the dominant deepwater benthic macroinvertebrate of the Great Lakes, contributing > 70% to the total benthic biomass at depths greater than 30 m (Cook and Johnson 1974). In other regions of North America, *Diporeia* are commonly found in large boreal lakes (Dadswell 1974) where temperatures are below 14°C. In North America, the range of the genus starts near the lower Mackenzie River, extending south and eastward through lakes in the Canadian Shield (including Lake Winnipeg), across the Great Lakes region and New York State. Their range ends in Quebec, in lakes within the St. Lawrence valley once having been connected to the glacial Champlain Sea (Figure 1). In other parts of the world the related *Monoporeia affinis* occurs in lakes of Scandinavia, northern Russia, and the Caspian Sea (Figure 1). This species often coexists with *Pontoporeia femorata* in the brackish waters of the Baltic, Bering, and Beaufort Seas. In North America *M. affinis* also exists in Ungava Bay and in parts of the Gulf of St. Lawrence. Similar to their North American counterparts, these two species are key benthic elements, in the Baltic Sea often comprising 90% of the total bottom fauna (Elmgren et al. 1990). There are believed to be three or more species of *Diporeia* in North America, but with their taxonomical separation still incomplete, we refer to them at the generic level in this paper.

Diporeia is described as fossorial, meaning well adapted for digging and burrowing in fine grained sediments. *Diporeia* inhabit the top few centimetres of the sediments, foraging for bacteria and searching the surface for organic detritus recently settled from the water column (Nalepa et al. 2005). During the spring diatom bloom, *Diporeia* will actively scavenge the sediments for deposited diatoms (Fitzgerald and Gardner 1993) which can contain up to 14% lipids based on their dry weight (Gardner et al. 1989). Through their continuous grazing *Diporeia* can increase their lipid values to as much as 50% of their dry weight (Gauvin et al. 1989). When preyed upon, *Diporeia* connect the spring algal blooms to the fish communities of the lakes they occupy, thus making them an important pelagic – benthic link (McDonald et al. 1990). Their efficient grazing can also magnify chemical contaminants thus making these substances available to food webs. In Lake Ontario, body burdens of perflorinated acid in foraging *Diporeia* can reach concentrations ten times greater than those found in the pelagic feeding *Mysis* spp. (Martin et al. 2004). Common thought was that this compound entered the food web solely via the pelagic region, but it has been shown that the benthic level was the main contributor, due to the voracious foraging of *Diporeia*.

In the Great Lakes, *Diporeia* have a two year generation time which results in three size classes: 7-9 mm adults, 4-6 mm juveniles, and young which are generally 2-4 mm in length (Dermott and Corning 1988). With their preference for cold environs, *Diporeia* contributed greatly to the benthic biomass in the Great Lakes at depth greater than 30m (Cook and Johnson 1974; Nalepa 1989). In 1990, amphipod densities in the Great Lakes typically averaged >3000 m^{-2} at depths between 30 and 60 metres, while maximum densities of up to 15,000 m^{-2} were recorded (Nalepa et al. 1998). The only exception were shallow areas such as western Lake Erie, where summer water temperatures are too warm for *Diporeia* to thrive due to the lack of a thermocline. For this reason, *Diporeia* are usually associated with the occurrence of cold/deep water fish species (such as lake whitefish, lake trout, deepwater and slimy sculpins) making them an important high lipid food source for these and other fish stocks (Owens and Dittman 2003).

In the 1990s, zebra mussels (*Dreissena polymorpha*) became established throughout the Great Lakes, preferring to colonize the warmer shallower waters along the shorelines and shoals. Around the same time, quagga mussels (*D. bugensis*) began colonizing the deeper parts of Lakes Erie and Ontario often to 60 meters (Mills et al. 1993). Where conditions were ideal for the invading dreissenids, they quickly formed blanketing colonies, filtering large volumes of water. In nearshore areas, filtering by the mussels increased water clarity, reduced nutrients, and phytoplankton density (Leach 1993; Markarewicz et al. 1999; Millard et al. 1999), and changed benthic populations and food-webs (Nalepa and Fahnenstiel 1995; Steward et al. 1998). These colonies have had the effect of removing a large portion of algae that would have previously settled offshore onto habitat populated by foraging *Diporeia* (Dermott and Kerec 1997; Nalepa et al. 1998).

A single adult *Dreissena* with a length of 20 mm can filter 100 ml of lake water per hour at 24°C (Bunt et al. 1993) via its inhalant (incurrent) siphon, removing particles as small as 0.7-1.0 µm in diameter under ideal conditions (Sprung and Rose 1988). In areas where mussel densities are large, they are able to change the algal composition of the water they occupy. Blooms of the cyanobacteria *Microcystis* have increased in Lake Erie and Saginaw Bay due to the selective rejection of cyanobacteria by *Dreissena* (Vanderploeg et al. 2001). The toxicant microcystin associated with this alga is known to cause mortality in crustaceans (DeMott and Moxter 1991) and it is believed that this toxin could be transferred to *Diporeia* via the colony's wastes.

Large mussel colonies consume large quantities of food. Particles not considered desirable enough to digest are combined with mucus and ejected via the mussels' exhalant (excurrent) siphon, large amounts of this expelled "pseudofeces" accumulates around the colony. Added to this biological debris are weak, old and damaged mussels which die off as the colony ages. Scientific authorities have recorded a recent increase in botulism in the Great Lake's fish and birds (Getchell et al. 2002) possibly caused by the bio-magnification by *Dreissena* of the paralyzing Clostridium toxins.

Benthic surveys of Lake Erie showed *Diporeia* density was beginning to decline in 1992 (Dermott and Kerec 1997) and by 1998 they were completely absent from samples taken from the deep cold waters (>20 m) of the eastern and the central basins (MacDougall et al. 2001). Johnson and Wiederholm (1992) showed that *Monoporeia* densities were linked to freshwater algal inputs and that any reduction to their food source has negative consequences to their abundance. Dreissenids had been only established for one summer in the lower Bay of Quinte (eastern Lake Ontario) before *Diporeia* rapidly disappeared at a 32 m site in 1993 (Dermott 2001) suggesting the presence of the mussels can bring sudden change. In Lake Ontario

between 1993 and 1997 the loss of *Diporeia* began to follow an established pattern; rapid loss of *Diporeia* from shallow waters followed by a decrease in abundance in the deeper colder waters (Dermott 2001; Lozano et al. 2001). Similar *Diporeia* population reductions have occurred in other Great Lakes, following the same pattern seen in Lakes Erie and Ontario where declines move from nearshore to offshore (Nalepa et al. 1998). Following the disappearance of *Diporeia,* local food webs were altered. In Lakes Erie, Ontario, and Michigan declines in commercial catches, poor body condition, and reduced reproduction rates of whitefish and smelt occurred. The abundance of forage fish (sculpins) in south eastern Lake Ontario had dropped by more than 95% between 1990 to 1996 (Owens and Dittman 2003).

With recent research being focused on the disappearance of *Diporeia* from the Great Lakes, we felt that smaller lakes within the Great Lakes watershed should not be overlooked. Questions raised were: 1) does the arrival of dreissenids forecast the extirpation of *Diporeia* from any given body of water they may coexist in; 2) was it possible that another stressor was occurring in the Great Lakes at about the same time; and 3) could the declines of the Great Lake *Diporeia* be incorrectly connected to the obvious exotic (dreissenids) while another other exotic (yet undiscovered) has spread outwards into smaller, more distant lakes causing an equally dramatic, yet unrecorded, decline in historical *Diporeia* abundances.

This study investigated if the decline of *Diporeia* in the Great Lakes is a localized effect restricted to lakes with *Dreissena*, or if their decline has become a regional occurrence in lakes around the Great Lakes - St. Lawrence watersheds. To accomplish this task, 14 smaller lakes (5 with *Dreissena* spp., 9 without), each with historical data on *Diporeia* abundances, were resampled.

METHODS

Recent *Diporeia* abundance was compared with historical data from a total of 14 lakes located in Quebec, New York State, Ontario, and Manitoba (Figure 2). The lakes sampled, their maximum depth, sampling interval (span), and when *Dreissena* spp. were first found in the lakes are listed in Table 1. If exact latitude and longitude coordinates were not available, transects were created along similar depth contours approximating those used in previous surveys by Green (1965), Dadswell (1974), Siegfried (1985), Dermott (1985 & 1995), Johnson (1988), and Flannagan & Cobb (1994). The Global Positioning Satellite (GPS) coordinates for the sites sampled in 2001-2002 are given in Table 2. Mike Dadswell (Acadia University) kindly provided maps of his original surveys showing the transect lines used. Figure 2 shows our sampling areas (abbreviated) within the Great Lakes - St. Lawrence watersheds, plus sites in Lake Winnipeg. Detailed individual lake diagrams are listed in the appendix. Wherever possible, site locations and sampling methods were matched to those used during previous surveys of the lakes to maintain consistent sampling efficiency between years. Sample site identifications, lake location, and year when samples were obtained are listed in Table 2; sampling devices used are listed in appendix 14.

A large 9" Ekman (area 0.05 m^2) was the sampling device used for most lakes. A total of 3 to 5 replicates were collected at 3-7 sites usually covering the depth range of the lake. The benthos collected was screened through a 580 µm mesh (US standard #30 mesh) screening bucket and the residual material then transferred into a standard 500 or 1000 ml Mason jar

depending on its volume. Sampling was done between the months of June and early October (2001 – 2003) during which time any young amphipods present would have been large enough to be retained by the mesh size. A smaller 6" Ekman (area 0.023 m^2) and a finer 250 µm screen were used in lakes George, Mephrémagog, and Winnipeg in order to match the methods used by Siegfried (1985), Dermott (1977), and Flannagan & Cobb (1994). Additional samples were obtained in Charleston Lake, Lake Cayuga, and South Bay after 2001.

Field samples were preserved at the time of collection using neutralized formalin, which was prepared from a solution of 37% formaldehyde to which $CaCO_3$ had been added two weeks before use. By using only two standard sizes of sample jars, field crews were able to accurately gauge the volume of screened benthos and accompanying lake water in each. This volume was then compared to a chart listing the amount of 100% neutralized formalin needed to bring the final concentration of formalin into the 8 - 10% v/v range needed for preservation. Approximately two weeks after the collection date, the formaldehyde was decanted through a four inch 180 µm mesh screen and the sample material rinsed onto a 9 inch 180 µm brass sieve (US standard #80 mesh) with cold tap water to remove any remaining traces of formaldehyde. The damp sample residue, including any organisms, was then returned to the original field jar and re-preserved with 50% isopropyl alcohol to which a minute amount of Rose Bengal had been added to aid in the staining of any organisms present.

Prior to sorting, the alcohol was decanted through an 180µm mesh screen and the sample thoroughly rinsed with cold tap water on a 9 inch 180 µm brass sieve. This step insured that alcohol-water convection currents, normally present when water and alcohol mix, would not interfere with the sorting process. To separate the benthos into its constituents, 5-10 ml aliquots were examined under a stereo dissecting microscope at 6X power. Any amphipods or *Dreissena* present were removed, identified to species and their numbers tallied using a nine unit laboratory counter. The biomass for each taxa was determined by first keeping the enumerated organisms, including fragments, moist in drops of distilled water in covered Petri dishes. When the sample was completely analyzed, this material was then removed from each Petri dish with forceps, blotted on filter paper to remove excess water, transferred onto a tared weighing boat, and weighed on an analytical balance to the nearest 0.01 mg. When *Dreissena polymorpha* and/or *Dreissena bugensis* were present the mussels were subdivided into 5 mm size classes (<5, 5-10, 10-15, 15-20, 20-25, >25 mm) and their number and wet weight (biomass) including shells for each size fraction determined. Newly settled *Dreissena* mussels <1 mm were not examined but returned to the remaining debris with other invertebrate taxa then re-preserved in the original jar using 50% isopropyl alcohol.

For each site, average density per Ekman sample, wet biomass, and the standard error were calculated for *Diporeia* and total *Dreissena* spp. present. For some of the sample lakes, the density of other taxa were compared to historical data. Density and biomass from lakes sampled with the smaller 6" Ekman were corrected to 9" Ekman equivalents before statistical analysis. The average density per lake was also calculated for each year of sampling. For this paper, 1992 was considered to be the last year that *Dreissena* was absent from all the lakes in the data sets. To test the effect of *Dreissena* on the *Diporeia* populations, statistical analysis of the count data was done using a Poisson regression with a log mean link (El-Shaarawi et al. 1987). The data was assumed to follow a Poisson distribution with mean $\lambda(Z) = \exp(Z' \beta)$, where Z is a vector of covariates and ß is a vector of unknown parameters. The covariates in our case are: the binary variable that indicates presence or absence of *Dreissena*, the depth, and the classification variable that refers to years. The statistical package S-PLUS was used to estimate the parameters of the model and their standard errors. A Poisson regression was done for: 1) all data, and again for; 2) lakes with *Dreissena* spp., and; 3) lakes without

Dreissena spp.. One way ANOVA was also used to compare *Diporeia* populations in individual lakes. Data from multiple years existed for Cayuga Lake and South Bay. For these two lakes, ANOVA's were done using the variables: site, year, and transformed counts per Ekman (ln(x+1)). Finally, a one way ANOVA was used to compare *Diporeia* values between years in Lake Winnipeg.

RESULTS

Two year classes of *Diporeia* were found to coexist in our study lakes during the sampling period (June through early October), a 4 to 6 mm (juvenile) group, and a < 4 mm (young) group. The larger mature adult group (7 to 9 mm), which reproduce in the winter and die after release of their young in early spring (March- April), were absent from our summer and fall samples.

During our surveys, only 5 of the 14 study lakes had resident mussel populations. Table 1 lists the lake abbreviations used in Figure 2, the year that *Dreissena* spp. colonized a lake, and years the amphipods were surveyed. Lake George was classified as a dreissenid lake, however since 1999 most of the mussels were removed from the limited areas where they had been found in the lake (John Wimbush, Darrin Fresh Water Instit., NY, pers. comm.). As of 2008, pockets of mussels have taken hold in numerous locations despite extensive eradication efforts. Lake Superior has localized colonies of mussels but overall calcium levels are too low for prolific *Dreissena* colonization. No *Dreissena* were seen in Batchawana Bay (Lake Superior) during 2001 and for this reason we classified Batchawana Bay as a non dreissenid area. In 2000, the first dreissenids were reported downstream and 4-6 kms east of our Charleston Lake sites (Tim Truesdell, Charleston Lake Provincial Park, pers. comm.). The distance separating the small colony from our sites and the direction of the lake's natural flow allowed us to classify our sampling area as non dreissenid in 2001.

STATISTICAL SUMMARY OF THE 14 LAKES

A Poisson regression was used to simultaneously analyze *Diporeia* abundance, depth distribution, and presence/absence of *Dreissena* in all 14 lakes over time (years). Examination of the deviance of the Poisson model showed no significant over dispersion or violation of the assumption, so the Poisson model is acceptable allowing it to be used to analyse the interrelationships. The Poisson model showed that: 1) the year differences (the average of all lakes compared over time) were not significant, however; 2) the presence of zebra mussels has a significant negative effect on *Diporeia* abundance; and 3) that depth had a positive effect on *Diporeia* densities (Table 3). The Poisson model predicted a Maximum Likelihood Estimate (MLE) for the negative effects of *Dreissena* presence as an expected reduction (15%) of amphipod density of the predicted mean (MLE = 0.85) in locations where dreissenids and *Diporeia* coexist (Table 3). The Poisson model also confirmed a corresponding positive effect of lake depth (0.9% increase of the predicted mean; MLE = 1.009) on density of *Diporeia* (Table 3).

When *Diporeia* densities in each study lake were compared against the abundance in all lakes simultaneously (n = 14) using the Analysis of Variance test (ANOVA), the resulting F ratio (*df* 13, 612 F = 62.14, p <0.0001) confirmed there were indeed significant differences in

Diporeia abundances between the 14 study lakes. These inter-lake differences were greater than the effects caused by the presence of *Dreissena* (*df* 1,624 F = 6.45, p = 0.01). The one way ANOVA statistical analysis of the *Diporeia* abundances performed individually for each lake's current and historical density showed that 4 lakes had significant declines in average *Diporeia* density, 3 had significant increases, while no significant changes occurred in the remaining 7 lakes studied (Table 4). Even in lakes with *Dreissena*, the ANOVA showed that habitat differences between the lakes had a greater effect on *Diporeia* density (*df* 4, 292 F = 219.36, p <0.001) than did the presence of mussels (*df* 1, 295 F = 0.57, p =0.45).

LAKES WITHOUT *DREISSENA*

Looking at only non dreissenid study lakes using Poisson regression, the *t*-value indicated that the population differences before/after 1992 was less significant (t = 4.7, Table 5) than the effect of increasing lake depth, which had a more significant influence (negative) on resident *Diporeia* populations (t = -12.9, Table 5).

This analysis coupled with whole-lake averages shows that *Diporeia* abundances have not declined regionally in lakes that can still be classified as non dreissenid (Table 5 and Figure 3). Concurrently, the 95% confidence interval for the MLE mean density in years after the arrival of *Dreissena* in the region versus sample years before their arrival was 1.058 to 1.147 (Table 5). This demonstrates that there was actually a slight average increase of 8.6% in *Diporeia* density over the entire time period of our data set between historical dates and 2001. The weak negative depth effect in lakes without mussels occurred because maximum depth sampled in these non dreissenid lakes (60 m) was less than in those lakes that had mussels (maximum 110 m). *Diporeia* were also absent at the maximum depths (50-60 m) in some of the lakes without *Dreissena*. The decline was much greater in Round Lake than that occurring in Lake Mazinaw, both non dreissenid lakes (Figure 3).

Comparison with the historical pre-1992 *Diporeia* densities for Charleston Lake, Lac Mephrémagog, Lake Winnipeg, and Batchawana Bay showed that there was only a slight decrease (non significant) in *Diporeia* abundance between individual sampling years (Table 4 and Figure 3). The historical depth distributions of *Diporeia* in Bernard, Blue Sea, Charleston, Mazinaw, and George Lakes as well as Lake Superior's Batchawana Bay shows an abundance profile characteristic of *Diporeia* across varying depths for most North American lakes (Figures 4-8). In these lakes, the highest density is typically between the 20 and 40 m depth range and overall the *Diporeia* population decreases as depth increases. The declines in Mazinaw Lake (Figure 6) show a shift in depth distribution similar to that which occurred in the Great Lakes from the 1990s to the early 2000s, where declines were greatest at shallower depths (Figure 9). Since the pre-1992 sampling, healthy increases (non significant) of amphipod abundance occurred in Turkey and Bernard Lakes at all sample depths (Figure 4). Lac Blue Sea's large increases (non significant) occurred only at sites shallower than 30 m (Figure 5), however these aforementioned increases were not significant when tested by ANOVA (Table 4). In Lake Winnipeg, there was no statistical difference in the average *Diporeia* densities between 1969 and 2002 (ANOVA *df* 1, 70 F = 0.27, p >0.61). It should be noted that in 2002, densities in Lake Winnipeg were greater only at 13 m and 17 m, compared to the historical 1969 values (Figure 10). Declines in *Diporeia* populations in Lake Winnipeg occurred at 7 m and 15 m depth zones (south and north basins respectively).

LAKES WITH *DREISSENA*

Of the five study lakes that had *Dreissena*, *Diporeia* declined significantly only in Lake Champlain and South Bay (Figures 11 and 12; Figure 3 and Table 4). During 2001, no *Diporeia* were found in any of the 30 benthic samples collected from the four sampling areas in Lake Champlain (Figure 11). The Poisson regression tested whether dreissenid presence had an effect on the resident *Diporeia* density over time. The calculated 95% confidence interval of the Poisson regression MLE for the five lakes with mussels ranged from 0.623 to 0.670. The highly significant *t*-value for year indicated that there was a statistically significant reduction of *Diporeia* in lakes with dreissenids present (Table 5). More specifically, the model calculated that the presence of *Dreissena* reduced *Diporeia* abundance to an average of 65% of the pre-invasion density (Table 5), which verifies the observed declines of *Diporeia* densities following the arrival of the mussels (Figures 3, 11, and 12).

In 2001, both George and Seneca Lakes had significantly higher densities than their historical densities of 1982 and 1918 respectively (Table 4 and Figure 7). *Diporeia* density in Cayuga Lake had also increased significantly since 1994 (df 3, 34 $F = 9.67$, $p < 0.001$; Figure 13). The increases in *Diporeia* populations in Cayuga and Seneca Lakes are anomalies compared to *Diporeia* populations in the Great Lakes where *Diporeia* do not co-exist well with *Dreissena*. To reiterate this key point, in both these New York State lakes, *Diporeia* abundance increased, however, only significantly in Seneca Lake (Figures 3 and 7). At 40 m depth, Cayuga and Seneca Lake's *Diporeia* densities were 3750/m^2 and 2290/m^2 in 2001 respectively. Mussel densities at 40 m in Cayuga and Seneca Lakes were 1640/m^2 and 900/m^2 respectively. Zebra mussels occurred as deep as 100 m in Cayuga and 110 m in Seneca Lake. In spite of direct competition with *Dreissena* for food and space at these depths, *Diporeia* densities were found to be 6364/m^2 and 1395/m^2 respectively in Cayuga and Seneca Lakes. Interestingly, dreissenid populations were 374/m^2 at 100 m in Cayuga Lake and 150/m^2 at 110 m in Seneca Lake.

Significant declines of *Diporeia* have occurred in South Bay (Figure 12) at various depths from 1961 to 2003. The 1981 *Diporeia* data for the 40+ depth zone shows a large population (146 *Diporeia* / 9" Ekman) which is incongruent within the entire Southbay data set. Johnson (1988) explained that error was introduced by selecting two of five profundal stations with a greater than average abundance of juveniles, creating a 1.5-1.8 times overestimation. The ANOVA comparing all four years of data (1961, 1981, 2001, and 2002) showed that the decline in *Diporeia* density over this 40 year period was significant (df 3,109 $F = 22.71$, $p < 0.0001$). A second ANOVA comparing the pre-*Dreissena* years (1961 and 1981) against the post 1997 *Dreissena* years (2001 and 2002) again showed that *Diporeia* densities declined significant (df 1, 111 $F = 65.01$, $p < 0.0001$) over this time period.

Sediments in South Bay differ based on depth. At depths <20 m, the bottom of South Bay is rocky, current swept, with little organic matter, well suited for *Dreissena* mussels but not *Diporeia*. At a 20 m site (site #7) *Dreissena polymorpha* averaged 1208/ m^2 in 2001 but decreased to 220/m^2 in 2003. At the same site, *Diporeia* declined from 80/m^2 in 2001 to 34/m^2 in 2003. At depths beyond 30 m, sediments in South Bay are a softer organic/silt mix, unfavourable habitat for *Dreissena*. At all the deeper sites sampled in South Bay, no *Dreissena* were found between 2001 and 2003. At a 37 m site (site #25) *Diporeia* densities steadily declined from a high of 464/m^2 in 2001, to 250/m^2 in 2002, and 160/m^2 in 2003, paralleling the downward trend seen in other regions of the Great Lakes after the establishment of *Dreissena*.

OTHER INVERTEBRATES

Over the last three decades density of other invertebrates have increased in many of the resampled lakes such as Batchawana Bay, Lac Mephrémagog, and Lake Winnipeg however the data from Turkey Lake were inconclusive. In Turkey Lake, where no human development has occurred, the decrease of invertebrates at the shallower 21 m site may have been due to the differences in sample dates (late May 1980 versus July 2001) following the summer emergence of that lake's chironomids and *Chaoborus*. At the deeper 27 m site in Turkey Lake there was no significant difference in invertebrate density between the 1980 and 2001 samples (tables 6a and 6b). In Batchawana Bay, the total abundance of most taxa increased, however the diversity of chironomids in the 1977 samples was similar to that in the 2001 benthos (Tables 6c and 6d) suggesting an enrichment of the bay that has not altered the community composition. In Lac Mephrémagog, density of the chironomids *Tanytarsini* and especially *Sergentia coracina* both of which respond negatively to low oxygen levels, decreased between 1972 and 2001 while oligochaetes increased suggesting a deterioration in water quality over the decades (Table 6e).

DISCUSSION

REGIONAL OVERVIEW OF THE GREAT LAKES WATERSHED

The negative effects of dreissenids on *Diporeia* populations are well known to those who study the amphipod; where dreissenids exist *Diporeia* abundances soon falter. This has been a repeating theme of many studies on the Great Lakes. Shifting the investigative focus onto smaller inland lakes with resident *Diporeia* population creates the question, "Did the 1990s arrival of dreissenids have a negative/positive affect on *Diporeia* populations beyond the confines of the Great Lakes"?

The St. Lawrence watershed (14×10^5 km^2) and Great Lakes watershed (7.5×10^5 km^2) are significant, covering much of Quebec, Ontario, and ultimately reaching into nine northern US states (New Encyclopaedia Britannica 1988). Tne initial selection criteria for study lakes within these watersheds included the following considerations: lakes with and without dreissenid populations; lakes with varying levels of dreissenid abundance; lakes close to or well removed from the Great Lakes proper; large deep lakes; small shallow lakes; remote/isolated lakes; and lakes with significant human contact/industries/activities in their catchments basin.

Candidate lakes needed to fulfill three more criteria, that being: 1) pre-dreissenid *Diporeia* sampling was carried out at various sites and depths; 2) there was a need for geographical separation so that local effects would be minimized; and 3) historical data was gathered over a wide span of years (between initial and final) in order to remove bias caused by manmade/natural environmental events. We narrowed our list to 14 lakes located mainly in the central and southern parts of the Great Lakes watershed, a few within the eastern region of the St. Lawrence watershed (Québec and New England), and a single lake west of the Ontario border. Some of our selected lakes were samples as early as 1918, but mostly in the 1960s, the 1980s, and the 1990s.

Data obtained throughout this large geographical area were analysed using whole-lake averages to look for the existence of a regional effect on *Diporeia* abundances. Averaging an entire lake's data into a single whole-lake average smoothes out dissimilarities in *Diporeia* density within a lake caused by various factors (depth, location, season, year, climate, fluctuating/migrating populations). This results in a value (average) that better indicates a lake's ability to support *Diporeia*. Graphing the 14 whole-lake averages (Figure 3) shows that only 4 of the 14 lakes (29%) exhibited a moderate to strong decrease over time. ANOVA's were done in order to corroborate the whole-lake averages, the results showed that 29% of our study lakes experienced a significant decrease in their *Diporeia* levels over time (Table 4).

These low percentages confirm the lack of a regional effect occurring within our study watersheds. A regional effect would have created declines in a larger number of our study lakes, including the 9 non dreissenid lakes. Instead, our observed findings showed 71% of our lakes had experienced either no change over time or an increase in *Diporeia* abundance (Figure 3 and Table 4).

LAKES WITH *DREISSENA* VS. LAKES WITHOUT: 14 LAKE POISSON REGRESSION

The whole-lake averages (Figure 3) and the significant changes listed in Table 4 reveal that the effects of dreissenids on the Great Lakes watershed are not wide spread but localized. The Poisson regression model confirmed this suspicion showing that dreissenids have a strong negative effect on *Diporeia* in lakes they cohabitate (Table 5). The 95% confidence interval for the (Maximum Likelihood Estimate) MLE of mean density in years after the arrival of *Dreissena* versus years before their arrival was 0.623-0.670. This range estimates that *Diporeia* density is about 65% of what had occurred before 1992 in lakes with mussels. The tight range of 0.623-0.670 also indicates a strong effect by a single influence (i.e. dreissenid presence) produced the reduction (≈35%) in the *Diporeia* populations.

A different picture emerges from the Poisson regression model on lakes without mussels. The 95% confidence interval of the MLE of the mean density in years after the arrival of *Dreissena* compared to years before was 1.058-1.147, indicating a slight increase in *Diporeia* density since 1992 (≈6-15%). Our study lakes encompass a large geographical area (Figure 2), a large MLE range indicates there are likely multiple environmental factors influencing *Diporeia* success when *Dreissena* are absent. The large spread of 1.058 to 1.147 reaffirms that when present, dreissenids have the ability to mask a wide range of environmental factors and singularly dominate *Diporeia* growth/fecundity. They do this via a strong, localized lake presence (0.623-0.670) that can obscure other naturally occurring factors, with the exception of lake depth, and to a lesser degree, year of sampling. This was shown by our 14 lake Poisson regression model producing a MLE value greater than one (1.009) indicating a positive effect on *Diporeia* abundance as depth increased within our data set. The significance of depth is well known in studies dealing with Diporeia habitat preferences (Marzolf 1965; Sandilands and Sly 1988; Sly and Christie 1992; Barton and Anholt 1997), however the depth factor is biased in our study due to two of the non dreissenid lakes (Round and Bernard) having no Diporeia present at their maximum depths (50-60 m). This depth range would be considered a mid lake zone for our deepest lakes with mussels (110 m). The depth distribution of the *Diporeia* populations in our study lakes are tabulated in figures 4-8.

SENECA AND CAYUGA: HYDROGRAPHICALLY PAIRED LAKES

The northerly tip of Seneca Lake is linked to the northerly tip of Cayuga Lake via the 20 kilometre long Seneca-Cayuga Canal/Seneca River system which flows northwards into the Erie Canal. The westerly end of the Erie Canal connects to Lake Erie at Buffalo on the Niagara River. Its eastern end connects indirectly to Lake Champlain via the Champlain Canal/Hudson River waterway (New Encyclopaedia Britannica 1988). The environmental implication of this canal system is significant; water and boats travelling from Buffalo (New York State) have transported aquatic invaders into Cayuga Lake, Seneca Lake, the Hudson River, and the more distant Lake Champlain with ease. Dreissenids present in Lake Erie were soon found down stream in Lake Ontario by 1991 (O'Neill and Dextrase 1994). By 1994 they had leap frogged ahead of their ever expanding territory to Lake Champlain as noted by Eliopoulos and Stangel (2000), proof of their ability to disperse quickly when aided.

Both Seneca and Cayuga Lakes had significant increases in *Diporeia* (p=0.005 and 0.031 respectively, Table 4) over time, which may be directly attributable to their physical similarities. Both are approximately 60 kms long, a maximum width of approximately 5.6 kms, with 170 km^2 of surface area (New Encyclopaedia Britannica 1988). Where they differ slightly is in their average depth, 89 m for Seneca Lake (188 m maximum depth) and 55 m in Cayuga

Lake (130 m maximum depth). Both also have steep bathymetry profiles. This may have created an environmental niche allowing *Diporeia* to flourish even after zebra mussels invaded these lakes. As in Lake Ontario, water deeper than 80 m may provide refuge for *Diporeia* from direct competition with *Dreissena* (Nalepa et al. 2003).

In these two Finger Lakes, a small change in horizontal distance is associated with a rapid change in vertical depth allowing *Diporeia* to easily migrate and forage the shallower sediments where food resources may be more adequate. Deeper sediments at Cayuga Lake's 100 m and Seneca Lake's 110 m sites contained a large quantity of leaf debris. This material slides down the lake's natural incline, past the shallow colonies of dreissenids who are unable to utilize this coarse organic debris. Fortunately *Diporeia* do not share this restriction and are able to feed on this particulate matter, including the bacteria it generates upon decomposition. Where this leaf material accumulates into a defined layer, it is provides additional protection from fish predation. This dual-purpose food source may be the reason a large number of *Diporeia* flourish beneath it despite their close proximity to dreissenids. Even at our deepest sites, dreissenid density was $150/m^2$ to $373/m^2$ while *Diporeia* densities were $1395/m^2$ to $6354/m^2$ in Seneca and Cayuga Lakes respectively.

Dreissenids were first identified in Cayuga Lake in 1991 followed by quagga mussels in 1994 (Mills et al. 1996). This 10 year period before our 2001 survey would have provided sufficient time for any negative ecological effects to have occurred to local *Diporeia* populations in both lakes (dreissenids arrived in Seneca Lake in 1992; (O'Neill and Dextrase 1994)). Our findings indicate that populations of *Diporeia* remained vigorous and have actually increased over time (Figure 7 and Figure 13). This increase is contrary to the Poisson regression model prediction of a 6-15% decrease due to mussel presence. In this case, environmental factors may have a more definitive role in *Diporeia* success. The readily available supply of coarse non filterable leaf material, ease of migration to shallow water sediments, and year round access to cold oxygenated deep water may be allowing both *Diporeia* and dreissenids to successfully inhabit the same areas.

Although the ANOVAs showed *Diporeia* have increased significant in these two lakes over time (Table 4), there is a strong case that historical levels (since 1918 in Seneca Lake (Birge and Juday 1921), 1964 in Cayuga Lake) may have been previously suppressed. Since the turn of the last century, Seneca Lake's *Diporeia* would have been negatively impacted by urban expansion and extensive use of agricultural fertilizers, both often resulting in eutrophication and reduced *Diporeia* density. Following this, the increased abundance of *Diporeia* in Cayuga/Seneca Lakes between 1964 and recent years (Figure 7 and Figure 13), would have been aided by the ban of phosphates in the 1970s and *Diporeia*'s natural density cycle (Johnson and Wiederholm 1992; Dermott 2001).

By becoming aware of the roles negative environmental factors play in a lake's health, the reversal of their effects via government regulations and close monitoring has allowed Seneca and Cayuga Lakes to return to a healthier state of existence. As positive environmental changes have gained momentum, they have ultimately allowed for a "significant" increase in *Diporeia* levels by negating much of the impact normally associate with the arrival of dreissenids, both real and statistical.

TROPHIC STATUS WITH OR WITHOUT DREISSENIDS

The presence of dreissenids in our study lakes was shown to have a negative effect on *Diporeia* (35% reduction of the MLE). Varying degrees of eutrophication may also be placing additional stress on *Diporeia* in lakes with or without a dreissenid presence. To analyze this interaction our final list of study lakes intentionally included five with varying degrees of phosphorus loading and dreissenid infestation: Lake Champlain (eutrophic with dreissenids); Lake Winnipeg (eutrophic without dreissenids); Lac Memphrémagog (mesotrophic without dreissenids); Lakes George and Charleston (oligotrophic with newly arrived dreissenids); and Blue Sea Lake (oligotrophic without dreissenids).

Lake Champlain: agricultural watershed

Lake Champlain has experienced significant changes to its *Diporeia* densities since the benthic survey of 1969. The ANOVA analysis (Table 4) showed a significant *Diporeia* decrease ($p = <0.0001$). In 2001, the New England Regional Office of the U.S. Environmental Protection Agency approved Vermont's list of Lake Champlain's "impaired areas" because they did not meet Vermont Water Quality Standards. Prior to this in 1990-1991, the mean total phosphorus concentrations in Lake Champlain exceeded the water quality criteria as set by the Vermont Department of Environmental Conservation authority (VTDEC) and the New York State DEC in 1997. By the mid 1970s areas of the lake were showing clear signs of eutrophication. In 1976, the average density of benthic organisms in the main part of the lake was 663/m^2 whereas approximately 6000/m^2 organisms could be found in Cayuga Lake, N.Y. (Wade 1976a). Wade (1976a) noted that organisms inhabiting Lake Champlain sediments were more characteristic of eutrophic species, especially in the shallower sampling areas. In 1965, thirty years before the 1994 arrival of dreissenids in Lake Champlain, Pantas (1966) stated that in Malletts Bay at the 28m site, oxygen levels ranged from <1.7 ppm in early September to <2.7 ppm at the end of the month (fall overturn). This early survey confirmed that Lake Champlain and its *Diporeia* population were dealing with serious environmental stresses.

Between 1969 and 2001 major *Diporeia* declines occurred at the shallow water sites, whereas abundances remained unchanged (non existent since 1969) at the deeper depths (Figure 11). When Pagel (1975) and Henson (1988) compared their benthic samples they found *Diporeia* levels well below that seen in 1969. A few pockets of shallow water *Diporeia* were present in 1992 and 1994, while at the 100 m mid lake site *Diporeia* absence continued (Eliopoulos and Stangel 2001). With Lake Champlain already impaired and its *Diporeia* population shrinking, the 1994 arrival of dreissenids may have dealt the final ecological blow. The predicted 35% reduction due to their presence, as indicated by the Poisson MLE (0.623-0.670; Table 5), would have been enough to push the remaining *Diporeia* to the point of extirpiration. This was confirmed by our 2001 survey which showed a complete absence of *Diporeia* at all of our sample sites.

Lake George: non agricultural watershed

Although only 2 kms separate Lake Champlain and Lake George, the width of Mount Defiance, their history of human use and industrial development has resulted in two very different lakes. Lake George is classified as oligotrophic, with phosphorus = 9 mg/m^3, Chlorophyll a = 0.8 mg m^{-3} and Secchi disk transparency of 7.4 m (Lake George Association 2007). Values for oligotrophic lakes are 4.1 - 9.0 mg m^{-3} for phosphorus, 0.82 - 2.0 mg m^{-3} for

Chlorophyll a and 15 - 7.8m for Secchi readings (Burns et al. 2005). Lake George is approximately 51 kms long, varying from 1.5 – 6.4 kms wide with a maximum depth of 61 m. In comparison Lake Champlain, with a much larger agricultural watershed, is approximately 182 kms long, 16 kms at its widest point, with a maximum depth of 122 m. (New Encyclopaedia Britannica 1988). Unlike other large lakes in New York State, Lake George is not connected to the Erie Canal, but drains into Lake Champlain via the 6 km long La Chute River (Ticonderoga, New York).

Despite this direct northerly connection to Lake Champlain, it was most likely boaters who carried zebra mussels into Lake George. The first colony was discovered in December 1999 in the southern tip of the lake just offshore of Lake George Village. In the spring of 2000 divers removed >19,000 zebra mussels from the area with an additional 1,800 being collected in the fall of the same year. A year later divers returned and removed 328 mussels, and in 2005 divers removed 55 zebra mussels. In 2003 another colony of 1500 mussels was removed near a private dock. When the same dock area was revisited in 2005 only 29 were found (John Wimbush, Darrin Fresh Water Instit. NY., pers. comm.). Despite their efforts, in 2007 mussels were found and removed from four new northern locations in the lake (Ticonderoga, Cleverdale, Sandy Bay, and Roger's Rock), these newer sites likely the result of multiple introductions (Lake George Association 2007).

In this report, Lake George was classified as having mussels based on their limited presence in 1999 to 2001, however like Lake Superior, it is Lake George's low calcium levels that will ultimately control their spread. Mussels have difficultly sustaining colonies when calcium concentrations fall below 15 mg $Ca \cdot l^{-1}$ (Cohen and Weinstein 2001) and individuals experience negative growth when calcium levels drop below 8.5 mg $Ca \cdot l^{-1}$ (Hincks and Mackie 1997). The Lake George Association (2007) reported that the average Ca concentration for the lake was 10.88 mg l^{-1}. More specifically, Hearts Bay in 2005 had a value of 5.1 mg $Ca \cdot l^{-1}$ whereas in the southern basin, near the village of Lake George, 16.5 mg $Ca \cdot l^{-1}$ was measured in 2004 (Lake George Association 2007). These values suggest that areas of the lake may remain dreissenid free allowing pockets of *Diporeia* to exist without their direct localized competition.

Our 2001 survey showed a significant increase in *Diporeia* density (p =0.041, Table 4) from the historical 1981 levels, these results contrast with those in Lake Champlain a mere two kms away. Despite the limited presence of dreissenids in Lake George, this oligotrophic lake showed a normal *Diporeia* depth distribution with the highest densities typically occurring between 20 m and 30 m (Dadswell 1974)(Figure 7). The comparison of these two lakes shows that environmental conditions (oligo/eutrophic, agricultural/non urbanised, Ca/P levels) play a critical role in the success and survival of *Diporeia* populations. Only continued analysis of Lake George's benthos will show how the *Diporeia*/dreissenid interactions will change over time and if the lake will experience a *Diporeia* reduction (35%), as strongly suggested by the Poisson MLE model.

Blue Sea and Charleston Lakes: cottage lakes

Two of our study lakes possessed healthy *Diporeia* populations with a classical depth distribution profile, these being the cottage lakes Blue Sea and Charleston (Figure 5). Blue Sea Lake is located in the Gatineau region approximately 85 kms north of Hull (Quebec) and the Ottawa River. The MLE range of 1.058-1.147 (Table 5) predicted that Blue Sea Lake's whole-lake average should have increased over time due the lack of dreissenids in its waters. This

was proven to be the case, however the increase was not large enough to be significant Table 4), this possibly due to the discovery of deep water *Thioploca* spp. in the sediments (Table 4). A large *Diporeia* presence occurred at the rather shallow 15 m site which had unusually cold sediments (6°C as recorded in early September). In contrast the preferable deeper 40-50 m sites contained fewer *Diporeia*, possible due to the limited presence of the sediment bacterium *Thioploca* spp.. Huettel et al. (1996) states that this bacterium prefers to populate dysaerobic sediments with oxygen levels at or below that considered ideal for foraging *Diporeia*. Despite the existence of *Thioploca* spp., the overall depth distribution for Blue Sea Lake showed healthy increases since 1971 as predicted by the MLE values in table 5.

The 1971 *Diporeia* survey of Charleston Lake revealed a depth distribution typical of most lakes in North America where the highest density occurs between 20 m and 30 m (Dadswell 1974). In 2001, the highest density of *Diporeia* was found at the 20 m site with reductions at all other depths. The only exception to this was the 60 m site which showed a slight increase over time. When viewed as a whole, this shallow water shortfall could be seen as the early stages of eutrophication due to human activity, however, the 2006 Charleston Lake Plan (Charleston Lake Association 2006) reported phosphorus values have dropped slightly from 1968 to 2003. This data indicates that eutrophication is not the central cause of the declines. The paper also states that summer DO levels drop in the latter part of August for most areas of the lake except the "Deep Water" strategically situated close to our 60 m site. As late summer oxygen levels drop, *Diporeia* would need to migrate to shallower more oxygenated areas of the lake (i.e. 20 m) thus creating a higher presence at these depths (Figure 5). This seasonal migration has the capacity of complicating the results of whole lake *Diporeia* measurements if sample sites do not take into account areas of naturally occurring DO fluctuations and *Diporeia* "safe havens".

Being a popular fishing lake only 11 kms from the St. Lawrence River, it took until 2000 before the first colony of mussels were discovered in Charleston Lake by local cottagers in a remote area removed from our benthic sampling (Tim Truesdell, Charleston Lake Provincial Park, pers. comm.). In the fall of 2005, *Dreissena* shoreline presence was confirmed during a visual survey by DFO field staff near areas of the lake sampled in 2001. In 2002, two Ekman samples were taken north of the 2001 60 m site. At site 35 m, *Diporeia* averaged 348 per Ekman in November of 2002 (range of 166 to 503) and 104 (range to 67 to 147; Appendix 14) in September of 2005, indicting a possible effect due to a now confirmed mussel presence. Another area not included in the 2001 study was a 40 m site located offshore of Crozier Island. At this site, through the month of June to September of 2005, *Diporeia* abundance averaged 177 over eight Ekman grabs (range of 111 to 275; Appendix 14). These are healthy numbers despite the proximity to extensive shoreline mussel colonies no more than 480 metres due east.

In July 2006 three replicates from the same 40 m site yielded an average of 134 (range of 108 to 160; Appendix 14), still healthy numbers but less than previously obtained. Due to the timing of the sampling, there exists the possibility that this average was strongly influence by fluctuating low oxygen levels occurring in the summer months and not the presence of dreissenids. Continued sampling is necessary in both George and Charleston Lakes to show if the recent arrival of dreissenids foretells *Diporeia*'s extirpiration (as in Lake Erie), or a successful co-existence, as observed in Cayuga and Seneca Lakes.

Lac Memphrémagog: the effects of ubanization

Lac Memphrémagog lies 100 kms northeast of Lakes Champlain and George in the province of Québec. Based on the MLE model for non dreissenid lakes, *Diporeia* densities in 200 should have increased by a factor of 6 to 15% (1.058 and 1.147), the spread between these MLE values implying an increase in *Diporeia* would be influenced by multiple environmental factors (Table 5). Our data showed that this expected increase did not occur, instead there was a non significant decrease in the whole-lake *Diporeia* average over time (Figure 3 and Table 4). Literature research showed that the MLE had correctly indicated that multiple environmental factors were occurring in this non dreissenid lake, however the model could not have foreseen that their complex interaction would not be additive.

We propose that there are five key water issues contributing to Lac Memphrémagog's complexity. First, the bathymetry of this freshwater lake is varied and is likely contributing the most to our observed whole-lake reduction (see Figure 9, Lake Erie's west basin). Between Newport (Vermont, USA) and Magog (Québec, Canada) the lake forms three distinct basins. The south, central and north basins have a maximum depth of 12 m, 107 m, and 33 m respectively (Kalff 1994), each of these depths would affect the success of *Diporeia*. Second, the lake has a distinct nutrient gradient; the southern end is mesotrophic, while the central and northern areas are oligotrophic (Simoneau 2004). This gradient is a result of the third factor; 71% of the lake's primary input of nutrients enters the southern basin via three rivers (Barton, Black, and Clyde) with the addition of the outflow from the recently constructed (1983) Newport's tertiary sewage treatment plant (Kalff 1994). The fourth, the main outflow of this lake is the Magog River which is controlled by a small scale hydroelectric development located at the northern end of the lake. This dam, built in 1883, has controlled water level fluctuations (Simoneau 2004) effectively altering Lac Memphrémagog's seasonal outflow and potentially influencing water quality by allowing nutrient accumulation similar to Lake Winnipeg's outlet control structure at Jenpeg (Manitoba). Further complicating these four factors is a fifth, the watershed surrounding Lac Memphrémagog continued to transport a larger quantity of nutrients into the lake's three basins over the study period despite a steady land use switch from agriculture to forest regrowth (Kalff 1994). Under normal circumstances, this land-use switch should have shown ecological benefits however recent urbanization pressures have negated any benefits via increased nutrient loads.

The term ecology was first officially coined by the German biologist Ernst Haeckel in 1866 (Merchant 2002) at a time when lakes in north-eastern US and southern Quebec were experiencing intensive urban development. Lac Memphrémagog avoided these pressures due to its mid-to-late 1800s drop in popularity which continued well into the mid 20th century (Kalff 1994). As the 1980s arrived, urban and tourism pressures increased around both the American and Canadian basins. In 2006 the VTDEC performed total phosphorus sampling and found values had significantly increased relative to state-wide norms. The Vermont Department of Environmental Conservation (2005) stated that Lake Memphrémagog's summer average phosphorus concentrations exceed criteria expressed in clause §3-01(A)-(2)-(c) of the Water Quality Standards.

An article by the Soil & Water Conservation Society of Metro Halifax (2006) states that phosphorus enrichment is manifested by an increase in oligochaetes which thrive in organically polluted habitats with lower dissolved oxygen. The increase oligochaetes between 1972 to 2001 at the 12 m Spinney Point site indicates sediment enrichment. At the same time, and possibly due to poor oxygen levels, a decrease occurred in the oxygen sensitive chironomids

Tanytarsini and *Sergentia coracina* (Table 6e). This correlated well with the observed 30% decrease in *Diporeia* abundances between the 1970s and our 2001 sample year. *Diporeia* abundances at the 15 m nearshore zone in 2001 were less than those found at the same site in 1972 (Figure 8). The near absence of *Diporeia* at 30 m in the deepest part of the north basin (Green Point) in September of both 1972 and 2001 suggests seasonal oxygen deficiency was restricting *Diporeia* distribution. Healthy populations of *Diporeia* existed throughout the deeper 40 m to 50 m depths indicating that in 2001 Lac Memphrémagog's nearshore *Diporeia* declines maybe directly related to increased phosphorus loading (eutrophication) or possibly undiscovered nearshore dreissenid colonies.

The negative effects caused by dreissenid presence on nearshore populations of *Diporeia* are well known (McNickle et al. 2006), but simply put, dreissenids must be present for there to be an effect. In Lac Memphrémagog *Dreissena* absence was validated by the VTDEC (2007) in cooperation with the Lake Champlain Basin Program who chose to include it in their 2005 Zebra Mussel Monitoring Program. The results of the VTDEC survey were conclusive, four years after our benthic survey showed zero mussel presence, they too confirmed the continued absence of dreissenids. Thus in Lac Memphrémagog, nearshore *Diporeia* declines (Figure 8) and increases in chironomids/oligochaetes (Table 6e) are most likely the result of water quality issues intertwined with multiple environmental factors, these events occurring in the absence of dreissenids.

Lake Winnipeg: eutrophication without dreissenids

Present day Lac Memphrémagog bears a resemblance to the state of Lake Champlain in the mid 1900s where eutrophication, not dreissenids, caused the largest decline in *Diporeia* (nearshore then deep water). Similar events are now occurring in Lake Winnipeg, the sixth-largest freshwater lake in Canada (Marsh 1985). This central Manitoba Lake was selected as one of our study lakes partly due to the large distance separating it from the Great Lakes (550 kms). Despite being disconnected from the Great Lakes shipping traffic, Lake Winnipeg is now dealing with aquatic invasive species such as *Eubosmina coregoni*, *Cyclostephanos dubius*, and rainbow smelt (*Osmerus mordax*). Yet by 2002 no dreissenids had been found in its watershed (Lake Winnipeg Stewardship Board 2006).

Covering approximately 24,390 km^2, Lake Winnipeg is 425 kms long and 40 to 109 kms wide with an average depth of 15 m (New Encyclopaedia Britannica 1988). The lake outlet control structure at Jenpeg (Manitoba) sets the monthly discharge between 25,000 m^3/s and 183,300 m^3/s (Marsh 1985), maintaining the water level at a constant 217 m above sea level. These limits alter the seasonal outflow and may impact water quality in terms of the potential for nutrient accumulation, the subsequent production of algae, and unsuitable habitat for *Diporeia* especially during the warmer summer months (Lake Winnipeg Stewardship Board, January 2005).

During the summer of 2002, the depth distribution of *Diporeia* in the shallow south basin of Lake Winnipeg suggested that the amphipods were restricted by elevated temperatures where depths were less than 10 m (Figure 10). In 2002 at depths greater than 15 m in the north basin the limiting factor is low oxygen levels as shown by the comparably small deep water populations (Figure 10). At the north basin site 26S we found a high density of the sediment bacteria *Thioploca* (198 g wet / m^{-2}) further proof of the existence of low sediment oxygen concentrations. Lake Winnipeg was further stressed in 2003 when it was stratified for as much as six weeks in mid summer creating hypoxia in the bottom water. The consequence

of this hypoxic event was that *Diporeia* were virtually absent from the deeper sites (>15 m) in the north basin in 2004 (Hann and Kowalchuck 2005). Additional surveys will be required to determine the magnitude of loss and if recovery has since occurred.

Based on the MLE model for non dreissenid lakes, Lake Winnipeg's *Diporeia* densities would be expected to increase 6 to 15% (1.058 and 1.147). By averaging the distribution of *Diporeia* across the whole-lake, figure 3 shows that despite the population shift by depth occurring in figure 10, the overall change in *Diporeia* abundance during the study period was a slight non significant increase (Table 4). The MLE prediction that multiple environmental factors would be present was shown to be correct (i.e. controlled outflow, presence of exotics, algae blooms, climate change, anoxic events, etc), however it could not predict that their complex interaction would result in a slight increase, the opposite of Lac Memphrémagog.

For Lake Winnipeg, there was no statistical difference in average *Diporeia* densities between 1969 and 2002 (ANOVA $df_{1,70}$ $F = 0.27$, $p > 0.61$) however, changes in densities were greatest at 13 m and 17 m, showing that abundances at these depth ranges have increased from the historical 1969 values (Figure 10). Our results in 2002 shows that total oligochaetes density increased from 485/m^2 in 1969 to 3969/m^2 in 2002, or 810% greater (Table 6f). *Trichopera, Chironomidae* and *Ephemeroptera* also increased since 1969. The increase of oligochaetes is a strong indicator of eutrophication however the increase in *Trichoptera* and *Ephemeroptera* (mostly *Hexagenia*) indicate oxygen levels were still adequate in 2002, unless densities of insects had been suppressed in 1969 due to insecticide use such as DDT.

During eutrophication, algae blooms can become a concern. In areas of Lake Erie and Saginaw Bay (Lake Michigan) for example, recent blooms of blue green algae have been linked to the selective rejection of cyanobacteria by *Dreissena* (Vanderploeg et al. 2001). Cyanobacterium are known to cause mortality in crustaceans (DeMott and Moxter 1991) and it is believed that the *Cyanobacteria*'s associated toxicant microcystin, could be transferred to *Diporeia* via the bivalves deposited pseudofeces. As dreissenids are absent from Lake Winnipeg, this transfer should not be of concern to the *Diporeia* foraging in its sediments. Unfortunately, Kotak et al. (1996) describes how in non dreissenid lakes, the food webs' primary consumers aid in the transfer of microcystin to higher trophic levels and ultimately to *Diporeia*. Since 1999 Lake Winnipeg's deeper north basin has had occurrences of fairly extensive *Cyanobacteria* blooms (Brenda Hann, University of Manitoba, pers. comm.) with chlorophyll levels above 40 $ug \cdot L^{-1}$ (Kristoferson et al. 2007). It is speculated that these water quality concerns are becoming more commonly connected with climatic issues.

Environmental data shows that Lake Winnipeg has begun to experience higher mean annual water temperatures which have changed the duration of open water on the lake (University of Manitoba 2008) resulting in increased stress on *Diporeia*. *Diporeia* need suitable habitat in order to survive and will actively seek out temperatures below 13°C and oxygen levels above 1 ppm. Global warming will create larger areas of the lake that have sediments too warm for *Diporeia* to survive in, yet their desperate search for cooler deeper sediments will be hampered by the presence of anoxic layers beyond 15 m. *Diporeia* declines during the mid 20th century in Lake Champlain were linked to environmental degradation, the last pockets disappearing after the arrival of dreissenids. Should *Dreissena* arrive in Lake Winnipeg, future events may unfold similar to Lake Champlain's, that being their arrival foreshadows the extirpiration of its *Diporeia* population (Table 5).

Batchawana Bay and South Bay: eutrophication and Dreissenid anomalies

Two of our study areas, Batchawana Bay (Lake Superior) and South Bay (Lake Huron), are directly connected to the Great Lakes. Batchawana Bay is in the northeast corner of Lake Superior, approximately 30 kms northwest of Sault Ste. Marie. In 2001, none of the benthic samples, nor rocks examined along selected shoreline sections of Batchawana Bay's shoreline contained mussels, allowing us to classify this bay as non dreissenid. Although reported in Lake Superior, the Lake's recorded low calcium levels of 13 mg Ca l^{-1} (Weiler 1978) have kept colonies of dreissenids localized to Duluth Harbor, Thunder Bay, Sault Ste. Marie, and Marquette allowing areas like Batchawana Bay to remain mussel free. Mussels will struggle to establish themselves in areas where the calcium levels are >13 mg Ca l^{-1} based on the research done by Mellina & Rasmussen (1994) and Cohen & Weinstein (2001) who determined this level was the minimum calcium requirement for the survival and growth of veligers.

The other study area, South Bay, is located at the south eastern end of Manitoulin Island (Lake Huron). This 26 kilometre long bay is divided into two distinct basins, the shallower outer basin connects directly to Lake Huron via a narrow channel less than 200 m wide. Our study area was the inner basin being 19 kms long, 6 kms wide, with a maximum depth of 59 m (King et al. 1997). *Dreissena* arrived in South Bay in 1997 even though they had been common in Lake Huron prior to this date (McNickle et al. 2006). Since the early 1960s South Bay has experienced steady *Diporeia* declines large enough to be considered significant (Figure 3, Figure 12, and Table 4). The opposite occurred Batchawana Bay where *Diporeia* increased slightly at all but the deepest sites sampled; these increases being statistically significant (Figure 8, Figure 3, and Table 4). These two events confirm the MLE predicted *Diporeia* population shifts based on the presence or absence of dreissenids.

McNickle et al. (2006) found that in South Bay oligochaetes increased in the shallow water zone due to the presence of dreissenids. Batchawana Bay had a similar increase in oligochaetes, chironomids, and Sphaeriidae at its 25 m and 32 m sites (Tables 6c and 6d). However in Batchawana Bay, human activity not dreissenid presence is the reason for these increases, with local cottage development and campground use having increased since 1978 (Charles Timmins, Fisheries and Oceans Canada, Burlington, pers. com.). Batchawana Bay's Tanytarsini density was nearly 10 and 44 times that found in 1978 at the same 25 m and 32 m sites respectively (Tables 6c and 6d). This degree of enrichment is normally associated with a decrease in *Diporeia*, however the opposite occurred. Brundin (1958) states that increases in Tanytarsini confirm sediment enrichment, however this chironomid is associated in areas of good water quality which would allow *Diporeia* to increase as well.

Although Batchawana Bay may be experiencing some degree of eutrophication, this does not appear to be the case for South Bay. King et al. (1997) felt that changes in thermal regimes in South Bay were not a result of eutrophication due to the lack of shoreline development over their study's time period of 1955 - 92. Similarly, McNickle et al. (2006) commented that phosphorus levels for Lake Huron's main basin have remained below the target levels of 5 µg l^{-1} since 1980 implying that South Bay's *Diporeia* declines could not be linked to phosphorus inputs (eutrophication) from Lake Huron. South Bay's significant decline of *Diporeia* was aided by the 1997 arrival of dreissenids (McNickle et al. 2006). Their effect was also noted in neighbouring Lake Huron in 2000 by Nalepa et al. (2007).

Unlike the collapse of *Diporeia* in Lake Erie and the Bay of Quinte after their the arrival of dreissenids, our 2001 survey of South Bay showed *Diporeia* were still present in spite of the mussel's 5 - 6 year presence. Historically in South Bay, there was a strong *Diporeia* presence

in all depth zones in 1961, with a steep decline occurring sometime between 1961 and 1981. This was then followed by a gradual decline from 1981 up to and including 2003 (Figure 12). With the largest decrease having occurred *before* the 1997 arrival of *Dreissena* in South Bay (McNickle et al. 2006), one can conclude other environmental factors were significant throughout this non dreissenid time period (1961-1997). Some of these are highlighted in the sections below.

SOUTH BAY, LAKE MAZINAW, AND LAKE BERNARD: PREDATION PRESSURES

Johnson and McNeil (1986) claimed that in 1972, *Diporeia* in the Bay of Quinte were poised for elimination due to heavy predation by *Morone americana* (white perch). This statement was proven accurate following the 1977 collapse of white perch in the Bay of Quinte demonstrating how one fish species can seriously affect *Diporeia*. With predation pressures removed, *Diporeia* levels rebounded to densities comparable to that in eastern Lake Ontario. In South Bay, *Coregonus clupeaformis* (whitefish) historically used *Diporeia* as their most important prey (Hart 1931) having up to 82% *Diporeia* by volume in their stomach contents (Ihssen et al. 1981; Reckahn 1970). At this consumption rate, anything causing a large fluctuation in whitefish stocks would have an equal effect on the Bay's *Diporeia* population.

This prey-predator relationship was exemplified by the arrival of *Petromyzon marinus* (sea lamprey) in Lake Huron. Lake Huron lamprey prey heavily on whitefish, this exotic reaching its peak abundance in 1948 (Berst and Spangler 1973). By 1965 the lamprey population had collapsed to a mere 10% of their 1940s levels resulting in a ripple effect felt throughout the lake. Annual commercial gillnet landings of whitefish for northern Lake Huron along the lake side of Manitoulin Island were at their lowest in 1961 ($4x10^3$ kg), with steady/healthy increases ($180 x10^3$ kg) occurring for the period ending in 1977 (Spangler and Collins 1980). Four years later in 1981, the benthos contained fewer amphipods than it did in 1961 (Figure 12), this a direct result of the depressed whitefish populations in 1961 having allowed larger numbers of *Diporeia* to flourish due to reduced predation.

Added to the natural decline in lamprey in the 1960s, chemical spraying of lampricide was extended to selected Lake Michigan and Huron streams between 1960 - 1969. Kaboni Creek, which discharges into the northern part of South Bay, was one of these chosen streams and was subsequently sprayed with lampricide in 1968, 1973, and 1978 (Sea Lamprey Annual Report 1978). As a result of this control in northern Lake Huron the abundance of lamprey declined and whitefish survival rates increased from 23% to 37% (Spangler and Collins (1980). A mark-recapture/genetic investigation by Ihssen et al. (1981) showed that whitefish of the inner basin of South Bay are cut off from Lake Huron population, in effect isolating them within the Bay. With lamprey populations crashing in Lake Huron, the Kaboni Creek treatments would have further reduced local lamprey thus indirectly affecting South Bay's *Diporeia* by increasing whitefish abundance within South Bay. It is this interwoven relationship between prey and predator (lamprey-whitefish-*Diporeia*) that resulted in the decline of amphipods in South Bay between the years of 1961 and 1981 (Figure 12), long before the arrival of dreissenids.

Predation may also have influenced *Diporeia* abundance in Lakes Mazinaw and Bernard. Lake Mazinaw supports a diverse fish population containing lake trout, lake herring (cisco), lake whitefish, yellow perch, northern pike, ling (burbot), smallmouth bass, brown bullhead, largemouth bass, rock bass, walleye (yellow pickerel), and pumpkinseed (sunfish)(Mississippi Valley Conserv. 2005). Although Lake Mazinaw has a total length of 14 kms, a narrow 25 m channel separates the north and south basins. Our study area was the northern basin measuring approximately 8.6 kms long by 4.4 kms wide. Between 1971 and

2001 moderate declines of *Diporeia* occurred at the 40 m and 60 m sites, with substantial declines occurring at the 10 m and 20 m sites (Figure 6). These large nearshore declines parallel changes that occurred following the *Dreissena* invasion of the Great Lakes (Lozano et al. 2001), however the Mississippi Valley Conservation (MVC) survey of Lake Mazinaw showed that dreissenid veligers were not present for the years up to and including 2006 (Susan Lee, MVC, pers. comm.). Similar to Lac Memphrémagog, other environmental factors control this lake's *Diporeia* populations.

The MVC have historically sampled both basins of Lake Mazinaw for water quality, averaging the data to create a whole-lake mean. The Secchi readings taken from their two stations in 2003 averaged 6.8 m compared to a shallower 5.2 m recorded 5 years earlier. Phosphorus concentrations at the same sites in 1971 and again in 2003 were 9.0 and 4.09 mg m^{-3}, respectively (Mississippi Valley Conserv. 2005). Reduced phosphorus levels would increase Secchi readings which are used as an indication of water clarity. These changes would have allowed: 1) increased light penetration and hence facilitate fish predation; and 2) increased infrared penetration to warm the sediments. The degree to which these two events occur is dependant on depth as shown by figure 6. Our field data shows that *Diporeia* inhabiting the shallower areas of the lake may have been severely affected by both events (warmer sediments and predation) whereas the deeper areas, removed from the effects of infrared warming, were impacted by predation as a result of this clearing over time.

Lake Bernard lies 195 kms northwest of Lake Mazinaw and being 8.2 kms long by 3.2 kms wide, is approximately the same size as Lake Mazinaw's north basin. With the absence of dreissenids in Lake Bernard, any changes occurring to this lake's *Diporeia* population would also be entirely due other non dreissenid factors. Contrary to our Lake Mazinaw findings, healthy increases of *Diporeia* occurred at all depths in Lake Bernard since 1972, however these were not statistically significant (Figure 4 and Table 4). As with South Bay and Lake Mazinaw, the predator/prey relationship appears to be important in this lake as well. Lake Bernard is promoted as an excellent year round trout fishing lake, a mere 200 m from Highway 11 which acts as an important hunting/fishing/vacationing artery. In 2005 in the Ontario Legislature, concerns were raised about the increased effort required to catch fish from Lake Bernard (Official Report of Debate (Hansard) 2005). Provincial restocking was requested in order to remedy the problem created by the lake's popularity. In the case of Lake Bernard, the ease of human access directly impacted local fish stocks which resulted in higher *Diporeia* abundances due to reduced fish predation at all depths (Figure 4).

SOUTH BAY AND ROUND LAKE: GLOBAL WARMING AND CLIMATE CHANGE

Temperature data from Environment Canada clearly demonstrates a rise in summer temperatures in the Great Lakes/St. Lawrence region of Canada (Environment Canada 2007). During the 17 year period from 1987 to 2003, 13 regional summer departures were hotter, 3 were cooler, and 1 had no change (Table 7). One of the three cooler years was directly connected to the 1991 eruption of Mount Pinatubo, an event that was felt globally (Pickering et al. 1997). In comparison, a similar period starting in 1957 up to 1971 showed 4 of the 15 regional summer temperature departures were hotter, a complete reversal of the latter part of the same century (Environment Canada 2007).

In September 2003 the MVC noted that temperatures in Lake Mazinaw were warmer than normal, indicating that the September (fall) turnover was delayed (Mississippi Valley Concerv. 2005). Likewise, our 2001 fall sampling of Round Lake (145 kms due east of Lake

Bernard) recorded a surface temperature of 17°C on September 26th indicating that it had not yet experienced its fall turnover. Recent fall water temperatures in the Bay of Quinte at Belleville (Ontario) show a similar pattern. Throughout a period of 10 years (1996 to 2006) a steady increase in fall temperatures can be seen (r^2 = 0.183). This trend is mirrored in Belleville's seasonal average water temperature values where a slow but steady increase in water temperatures is detected (r^2 = 0.63) (Jocelyn Gerlofsma, Fisheries and Oceans Canada, Burlington, pers. com.). All of the above findings are exemplified in a phenology (ice-on) study of Turkey Lake. Over a 26 year period ending in 2006, the date on which permanent ice occurs on Turkey Lake has increased from November 9th to December 15th (r^2 = 0.88)(Government of Canada 2008). A study of South Bay's response to climatic variability from 1955 to 1992 showed that thermoclines had become shallower and epilimnetic temperatures had increased (King et al. 1997). In South Bay, this would have biological implications such as changing the timing of the larger inner basin's fall turnover and its earliest stratification date (King et al. 1997). King et al. (1997) also states that shortening the length of time until the formation of the thermocline would reduce the duration of the spring diatom pulse. This would ultimately have a negative effect on both the production of diatoms and *Diporeia's* growth/fecundity; but are these two events necessarily linked?

Johnson and Brinkhurst (1971) confirm this link by noting that in Lake Ontario, growth efficiencies of *Diporeia* were highest during the spring and decreased during the summer months indicating that the diatom bloom provides a vital portion of *Diporeia*'s energy allotment for the year. Sly and Christie (1992) also observed that in Lake Ontario other major benthic fauna (oligochaetes) increased with the advance of summer signifying they extracted most of their requirements from the summer's phytoplankton production, not the spring diatom bloom. With both of these studies confirming the importance of diatoms to *Diporeia*, one needs to ask if some areas produce more diatoms than others. The sediment below a diatom "hot spot" could act as a *Diporeia* "food magnet". As in the case of Charleston Lake, this type of population shifting would play havoc with population estimates using few sample locations.

Studies in Lake Ontario have shown that phytoplankton biomass is higher in the near and mid shore regions, with the offshore region being much less productive (Munawar and Munawar 1996). The inshore springtime phytoplankton biomass ranged from 1 - 7 gm^{-3}, with 58% of this composed of diatoms. This correlates with the fact that *Diporeia* are denser at the nearshore depth and less numerous at the mid lake sites, a phenomenon linked to stronger near shore mixing, a key event in diatom production. The majority of diatoms reproduce during the spring when silica levels are high and the cold water is dense enough to keep them afloat. Currents lift them repeatedly to the surface where they use the available silica during their growth and reproduction cycle. This rise and fall persists until the diatoms become too heavy, at which point they gradually sink below the active-mixing zone and cease to multiply. With the shallow water zones producing a larger number of mixing cycles, a greater number of diatoms are deposited onto sediments below this area when compared to the offshore zone.

Diporeia are food limited; population fluctuations have been attributed to changes in food availability (Sarvala 1986). Reduced diatom availability would have the effect of gradually lessening *Diporeia* recruitment. In South Bay the shallow water zone should produce more diatoms due to the higher number of mixing cycles, however less food is available to *Diporeia* due to the highly efficient filtering action of dreissenids. The presence of dreissenids and unsuitable habitat (rocky) would ultimately prevent large nearshore *Diporeia* populations from forming as confirmed by figure 12. McNickle at al. (2006) found that in South Bay after the arrival of dreissenids, *Diporeia* remained absent from the shallow water zone (0-10m), a slight

increase occurred in the mid water zone (11-30m), and a considerable decrease took place in the deep water zone (31-57m).

Our 2003 mid water 20 m and 30 m zones mirrored these results, showing slight increases in *Diporeia* abundance possibly due to a population shift caused by competition with driessenids (Figure 12). McNickle et al. (2006) dismissed their 2003 *Diporeia* increase (slight) in their mid-water sample zone (11-30m) as an error generated by historical sampling practices, however this increase may indicate that two key physical factors are present: the negative effects of nearshore filtering by dreissenids causing a *Diporeia* migration to the slightly deeper, more fertile mid zone sediments; and the more recent effects of warming on the thermocline. King et al. (1997) stated that warmer years would create: an earlier stratification date, a later turnover date, a shallower midsummer thermocline, a warmer epilimnia, and a larger maximum temperature difference between the epilimnion and the hypolimnion. Either individually or in combination, these factors would decrease the amount of diatoms produced in South Bay and a decrease diatom production would impact directly on *Diporeia* abundance.

Could this fact explain the creation of a mid zone spike? Even with a Bay wide diatom reduction occurring, there would be a proportionally higher (albeit less) volume of diatoms produced in the near/midshore zones than the normally less productive deep water zone as described by Munawar and Munawar (1996). Added to this, the highly efficient filtering action of the large nearshore colonies of dreissenids could easily strip the nearshore area of South Bay's compromised springtime production of diatoms leaving few diatoms to settle safely to the bottom. With mid zone dreissenid abundances being smaller than the nearshore, a proportionally larger number of diatoms would successfully settle onto the mid zone sediments. A larger diatom deposit would beckon all foraging *Diporeia* and by so doing create a population shift similar to that observed in figure 12, where amphipods move away from low diatom production areas. To summarize, figure 12 may indicate that over the years South Bay has been dealing with environmental instability leading to diatom reductions due to: the recent arrival of dreissenids which had a real and statistical negative impact of 35% based on the Poisson regression MLE (Table 5); the Bay's observed thermocline changes since 1955 as noted by King et al. 1997); and Environment Canada's 1987-2003 observed 17 year warming trend (Table 7).

The effects of a warming climate may also help explain our Round Lake data. Round Lake, at the time of the 1971 survey, had healthy levels of *Diporeia* across all depths. By 2001 there was a significant lake wide decrease ($p = < 0.0001$) of *Diporeia*, the largest declines occurring at the deep water sites (Table 4). If King et al. 1997 stratification effects were extended to this lake, the observed changes could signify a strong climatic effect on the epilimnion and diatom production. The 2001 fall sampling in Round Lake recorded a surface temperature of 17°C on September 26th indicating that it had not yet experienced its fall turnover. A delayed turnover would create dissolved oxygen issues for the deeper sediments, this caused by the creation of shallower thermoclines and increased epilimnetic temperatures occurring over longer periods (King et al. 1997).

Being a smaller lake (7.7 kms by 5.3 kms) the lack of mixing, as a result of earlier/stronger spring time stratification, would seriously affect this lake's ability to produce diatoms and aerate its deep water. As with Lake Winnipeg, deep water *Diporeia* would be forced to move to shallower more oxygenated areas during periods of prolonged stratification. This would potentially leave them vulnerable to warmer less productive sediments and increased competition for food with *Diporeia* normally present in those areas. Lipids obtained from settled diatoms are vitally important to *Diporeia* females for the production of eggs

(Cavaletto et al. 1996). Quigley and Lang (1989) concluded that lipid storage allows for the maximum exploitation of transient food sources (spring diatom pulse) necessary for future metabolic needs, i.e. fall/winter reproduction. Repeated years of abnormally high temperatures would affect *Diporeia*'s ability to grow and survive in this deep zone, producing the results observed in figure 6.

TURKEY LAKE WATERSHED: GLOBAL WARMING AND ACID RAIN

The lack of oxygen caused by stratification has been a limiting factor for successful *Diporeia* colonization of Turkey Lake's deep water sediment for many years. Turkey Lake, one of four lakes in the Turkey Lake Watershed (TLW), is located approximately 60 kms north of Sault Ste Marie and 15 kms northeast of Batchawana Bay (Lake Superior). This watershed is a remote, undisturbed, completely forested basin (mixed hardwoods), used in the mid 1980s as one of five hydrologically "calibrated" basins in eastern Canada for scientific research on the effects of acid rain on aquatic ecosystems. More recently, it has produced data showing the effects of global warming.

In Turkey Lake the complete absence of *Diporeia* from the 35 m sediments in 1980 and 2001 is caused by three key factors: 1) Turkey Lake is dimictic; 2) the 35 m benthic sediments contain 29-36% organic material (Dermott 1988); and 3) at this depth dissolved oxygen is <3 mg l^{-1} which allows the high predominance of *Chironomus* over all other species (56 chironomids, 5 oligochaetes, 0 *Diporeia* / 9" Ekman). In comparison, *Diporeia* and Tanytarsini were found at the 21 m and 27 m sites indicating better oxygen levels (Tables 6a and 6b). The observed decrease in chironomids at the shallower site (21 m) may have been due to the differences in sampling dates, late May 1980 versus late July 2001, the latter sampling date occurring after the cyclical summer emergence of chironomids (Table 6a).

Langlois et al. (1983) discovered that in 198 headwater lakes located in the Precambrian shield of Québec a low pH of 5.0-5.5 reduced the total density of all benthic organisms with a corresponding reduction in biomass. The TLW is a similarly sensitive watershed with thin Precambric soils devoid of calcium carbonate and other cations at higher elevations. As acidic precipitation accumulates as snow, the frozen soil is unable to neutralize the deposited sulphates suspended above. During the spring melt, accumulated acidic precipitation flows into the lake largely unbuffered having the potential of dropping pH low enough to seriously stress *Diporeia* and their newly hatched young. From 1982 to 1999 in the TLW there was a 48% decrease in the annual atmospheric sulphate deposition (37 kg/ha to 18 kg/ha) (Government of Canada 2007). This sulphate reduction would have lessened the spring acid shock event allowing increased amphipods survival, which may be a reason for the population increases seen at our Turkey Lake sites.

To summarize, factors responsible for *Diporeia* population changes in TLW are: phenological changes due to climatic shifts (decrease); Pontoporeiidae interannual density cycles (increase/decrease) (Johnson and Wiederholm 1992; Dermott 2001); and increasing watershed pH due to reduced sulphate emission (increase).

SUMMARY

An ecosystem is the interacting synergism of all living organisms ultimately forming a complex web of interdependency. Regardless of an aquatic ecosystem's size, environmental stresses created at any level, either man made or natural, have a potential domino effect on every other occupant of that system (National Safety Council 2005).

Resampling historical *Diporeia* lakes has shown there is no evidence of a regional decline in *Diporeia* populations in the Great Lakes/St. Lawrence watersheds. Decreases can be linked to the presence of dreissenids however the presence of *Dreissena* does not guarantee the extirpiration of *Diporeia*, as shown by the viable populations of *Diporeia* in Cayuga and Seneca Lakes. Within the 14 lakes sampled, the 14 lake ANOVA showed that habitat differences between lakes had a greater effect on *Diporeia* density than the presence of mussels. Lake Champlain and South Bay demonstrate environmental stresses create large declines in *Diporeia* numbers. When stresses are removed Bernard, Seneca, Cayuga, and Turkey Lakes showed that *Diporeia* populations can rebound. In light of current environmental changes, continued analysis of Seneca, Cayuga, Charleston, George, and Blue Sea Lakes would present an opportunity to further explore the combined effects of the dreissenid expansion in conjunction with global warming, and to monitor *Diporeia*'s (SOLEC Indicator # 123) ability to act a "benthic thermometer" in these ancient *Diporeia* strongholds.

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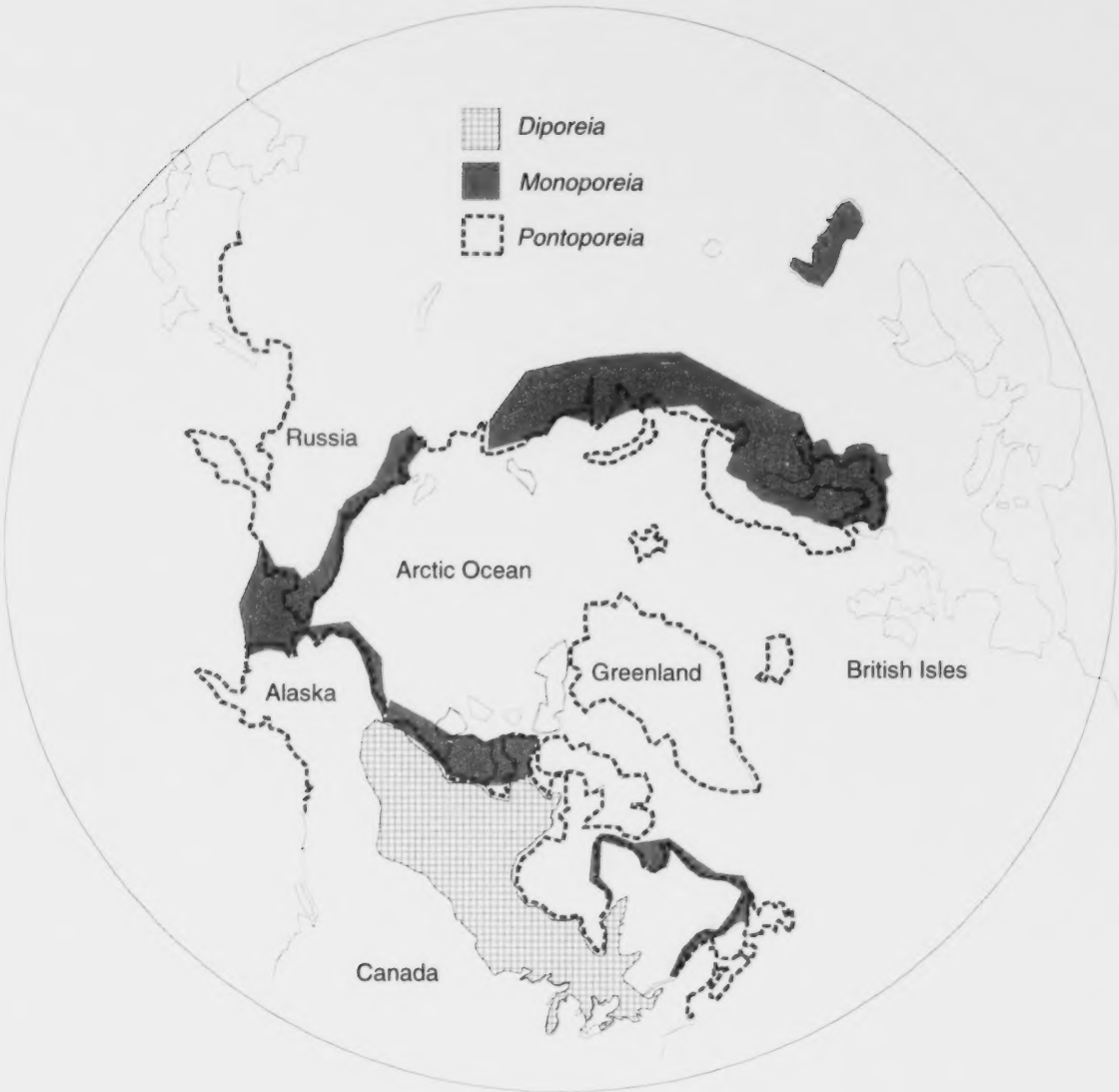

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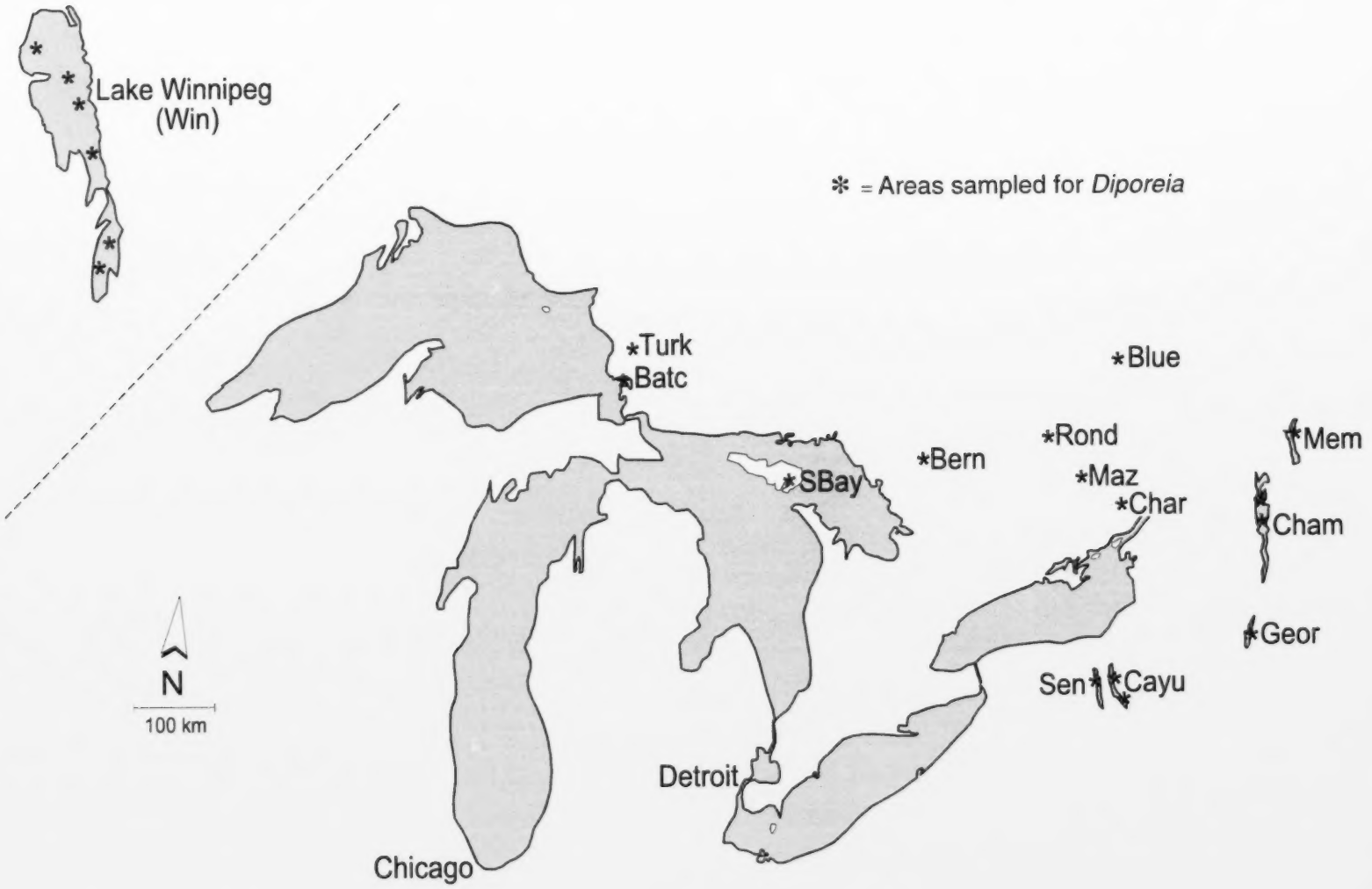

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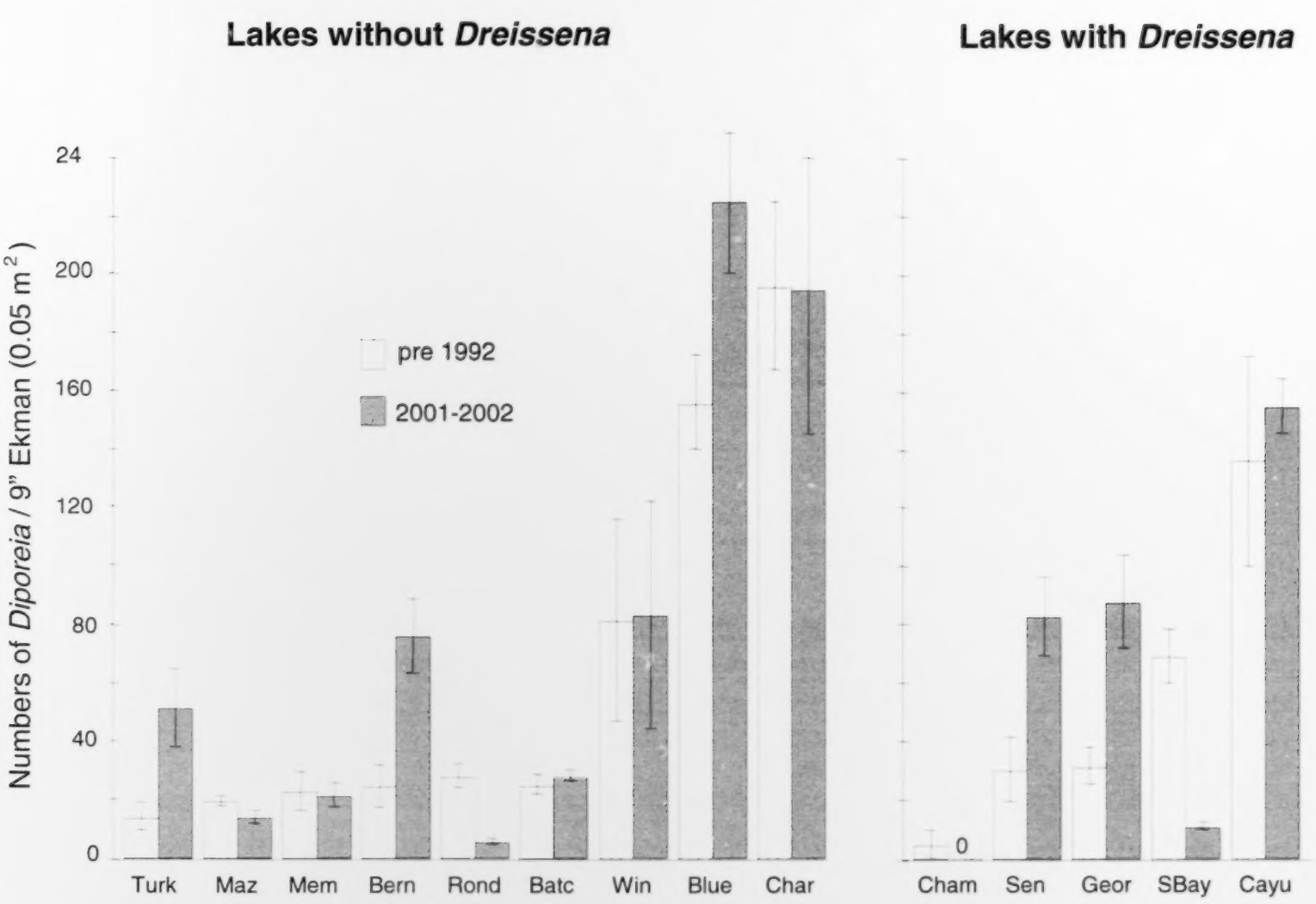

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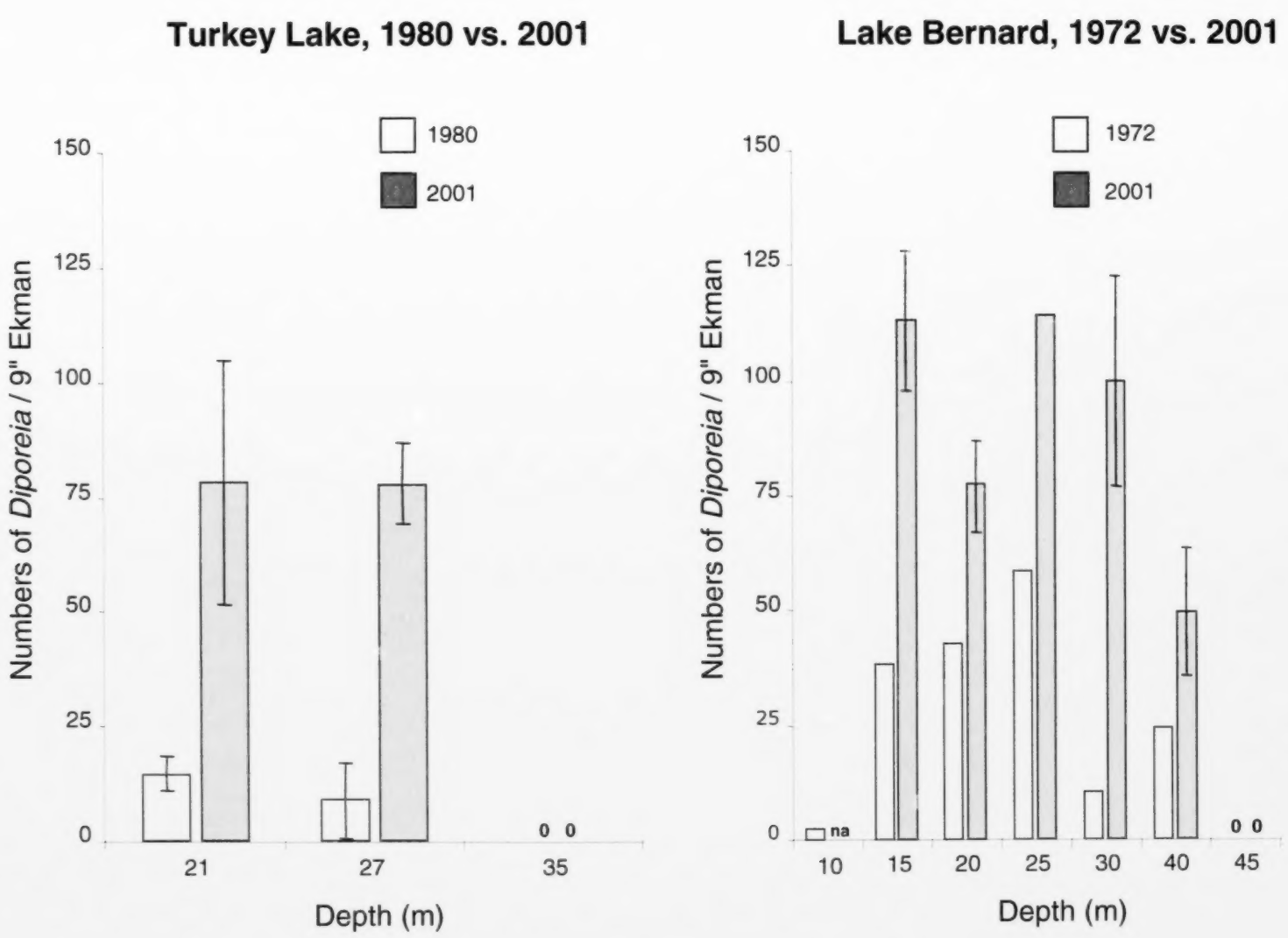

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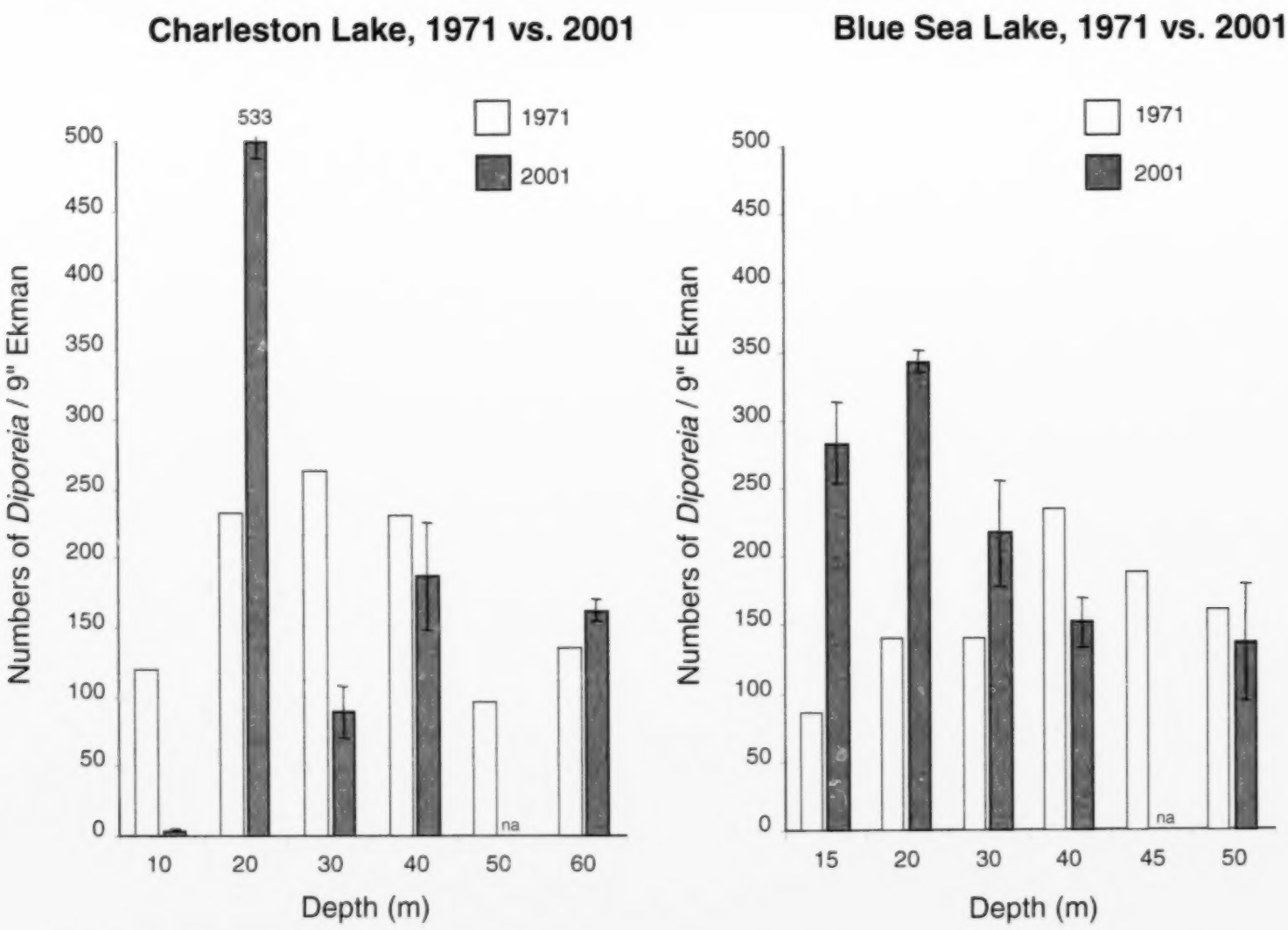

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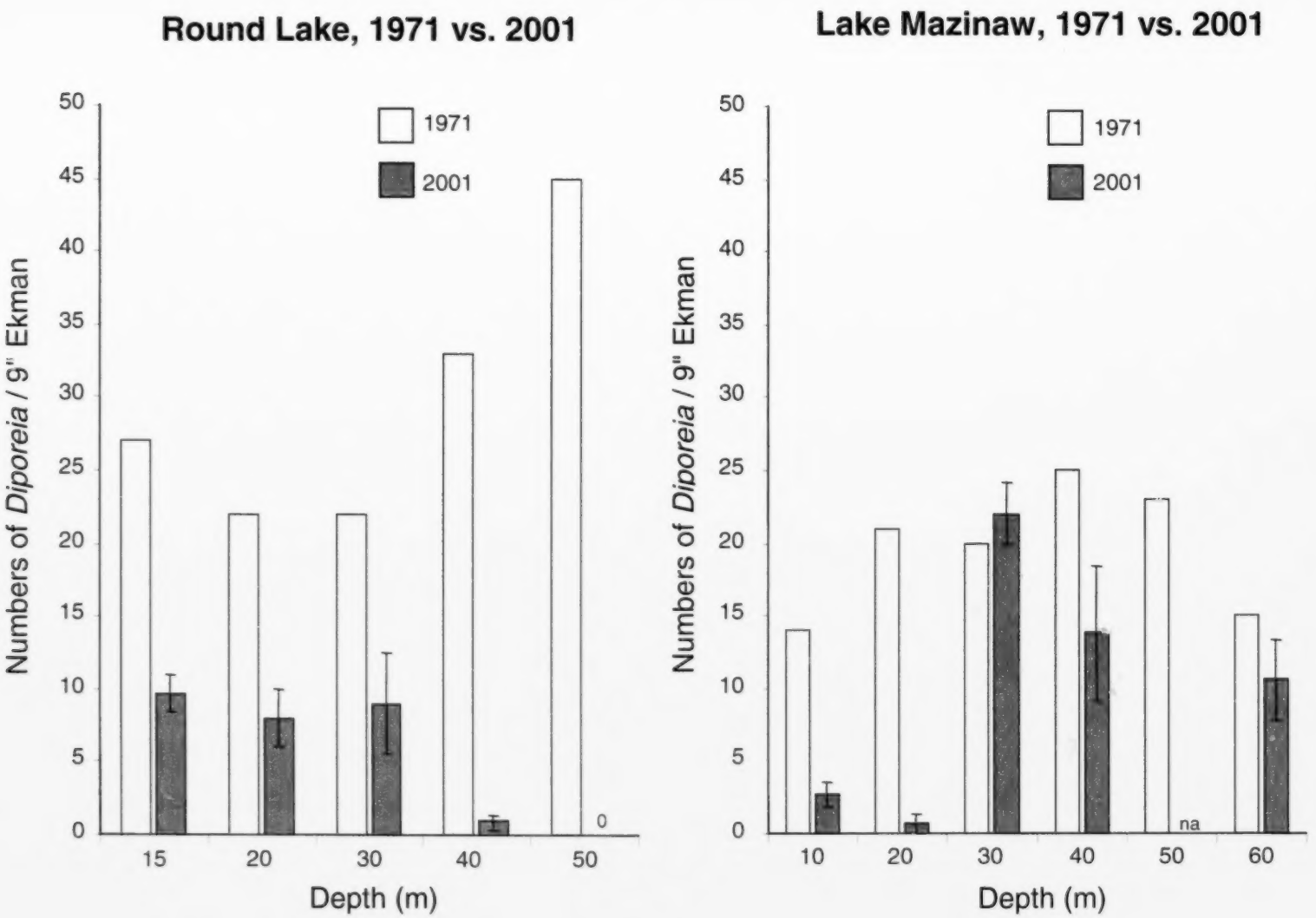

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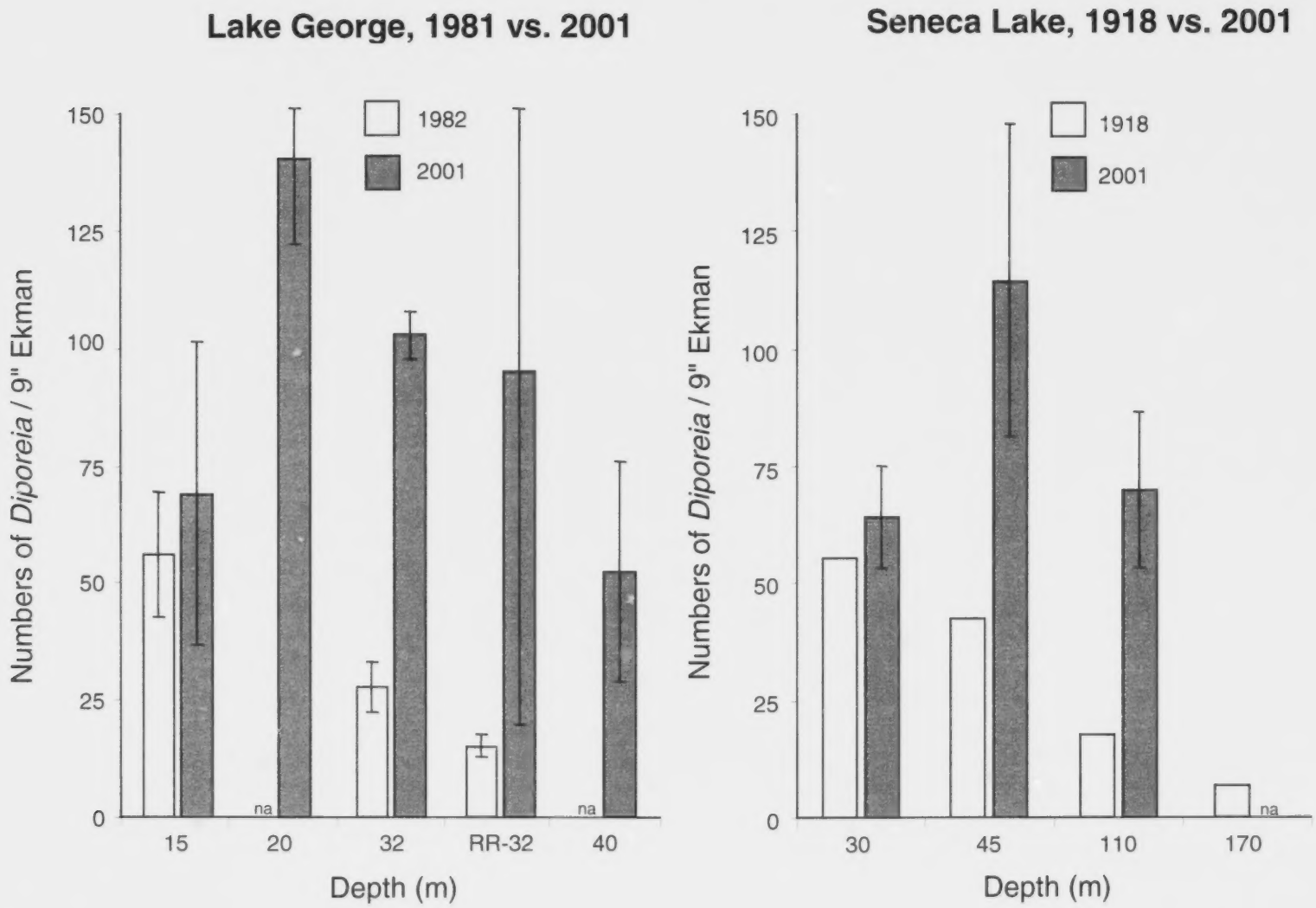

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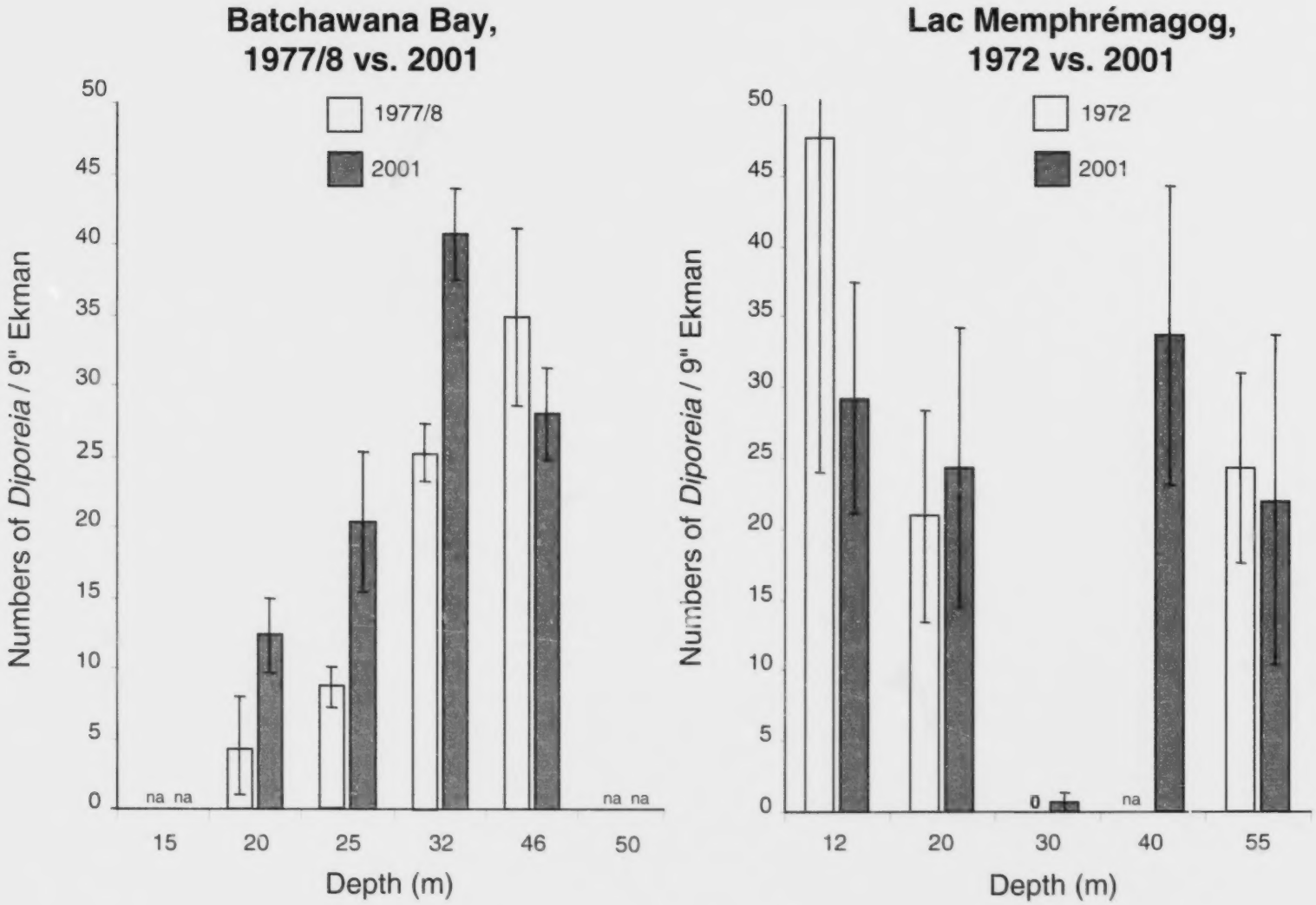

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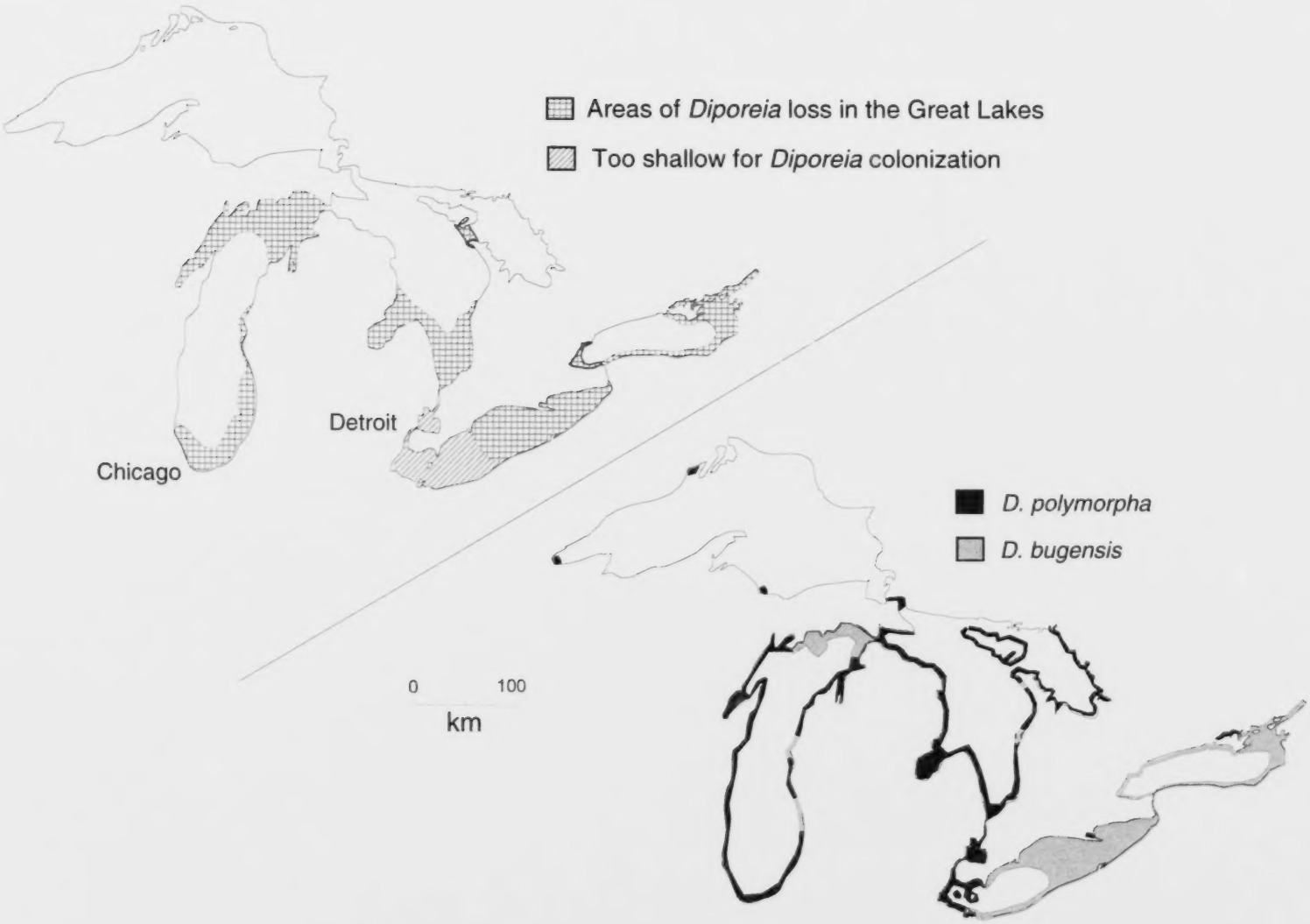

Figure 9. Areas of *Diporeia* loss and the distribution of *Dreissena* in the Great Lakes from the 1990s to the early 2000s.

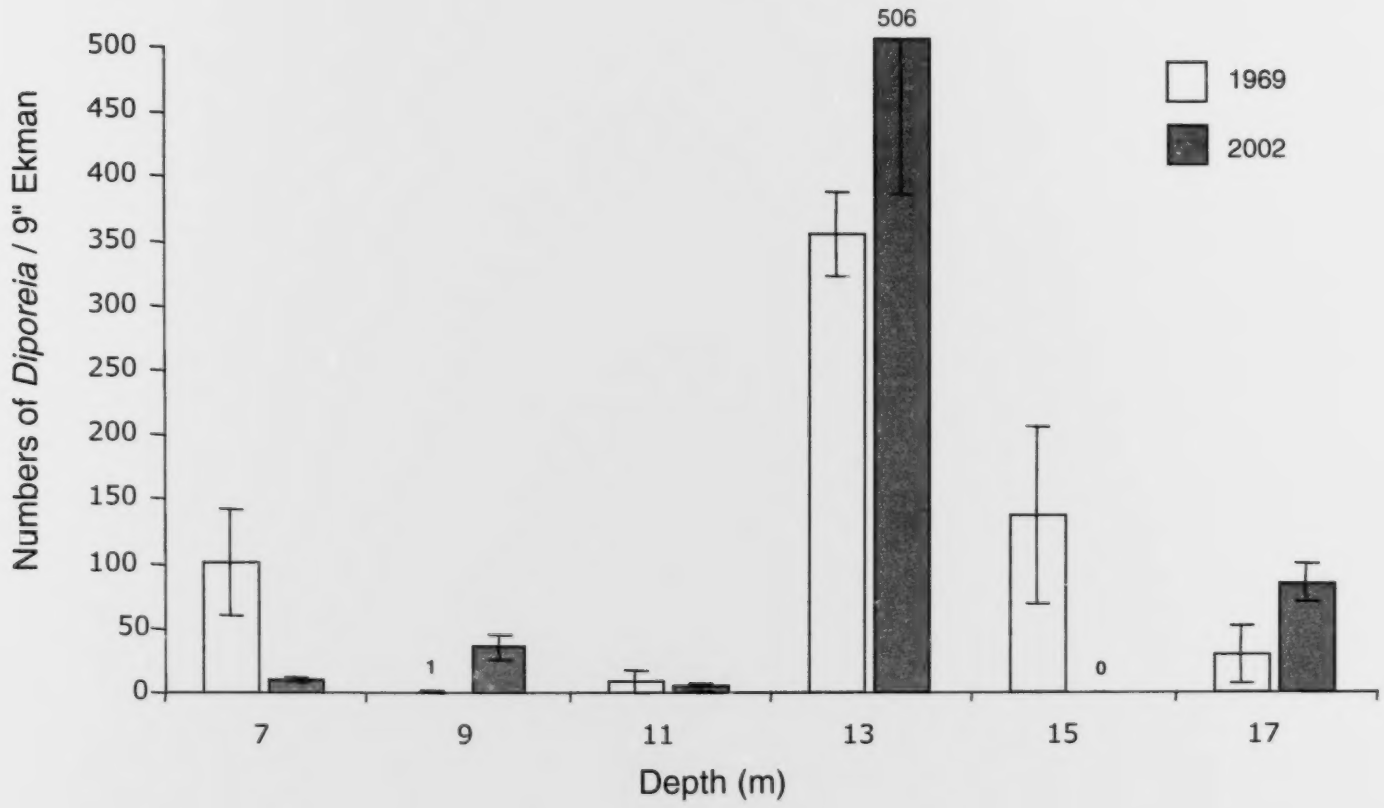

Figure 10. Density of *Diporeia* per 9" Ekman sample (equivalent area) in Lake Winnipeg at various depths (m) in 1969 and 2002.

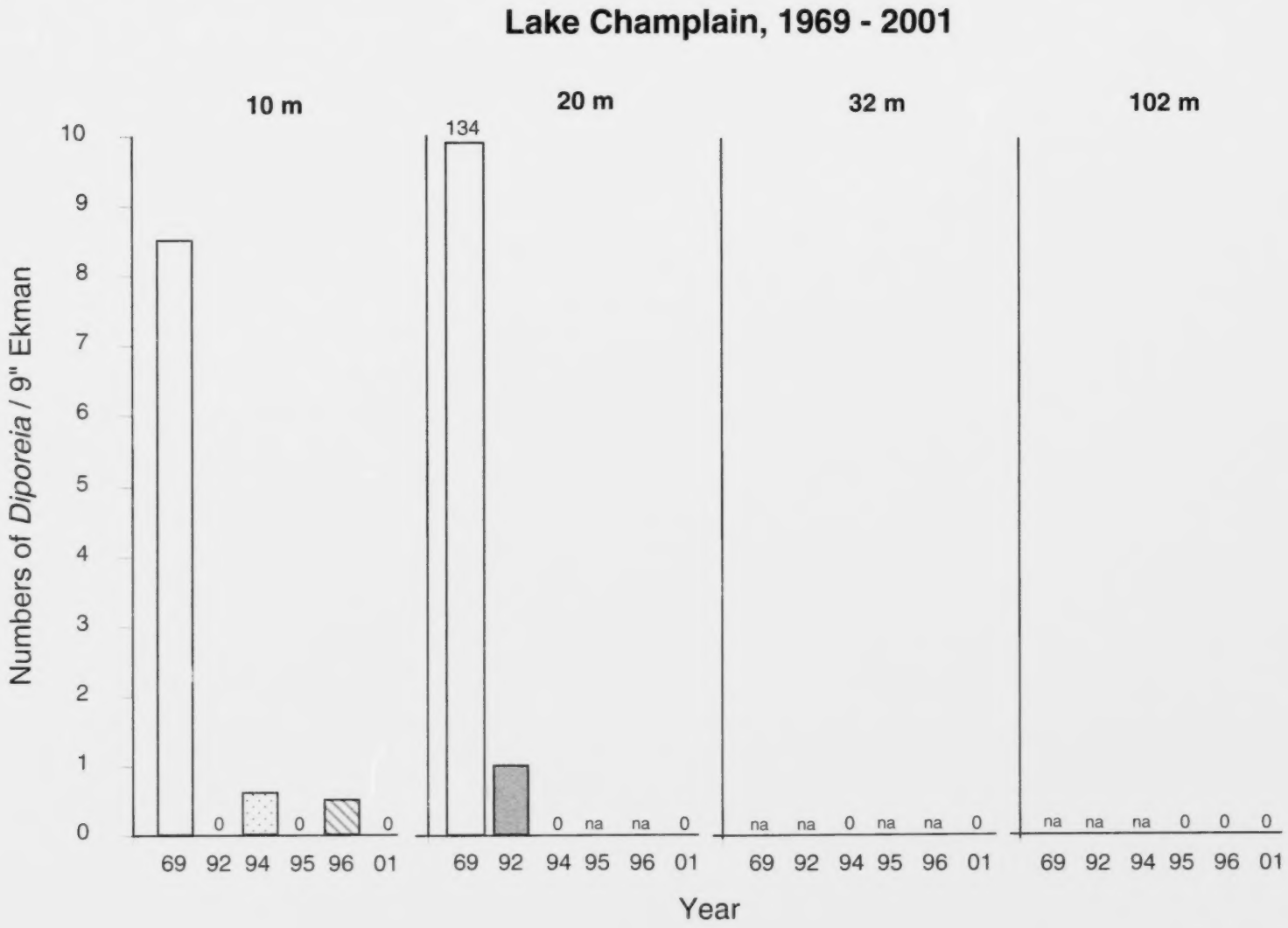

Figure 11. Density of *Diporeia* per 9" Ekman sample in Lake Champlain at various depths (m) in sample years 1969 through 2001, na = not available, data from Peter Strangel (Vermont Natural Resources).

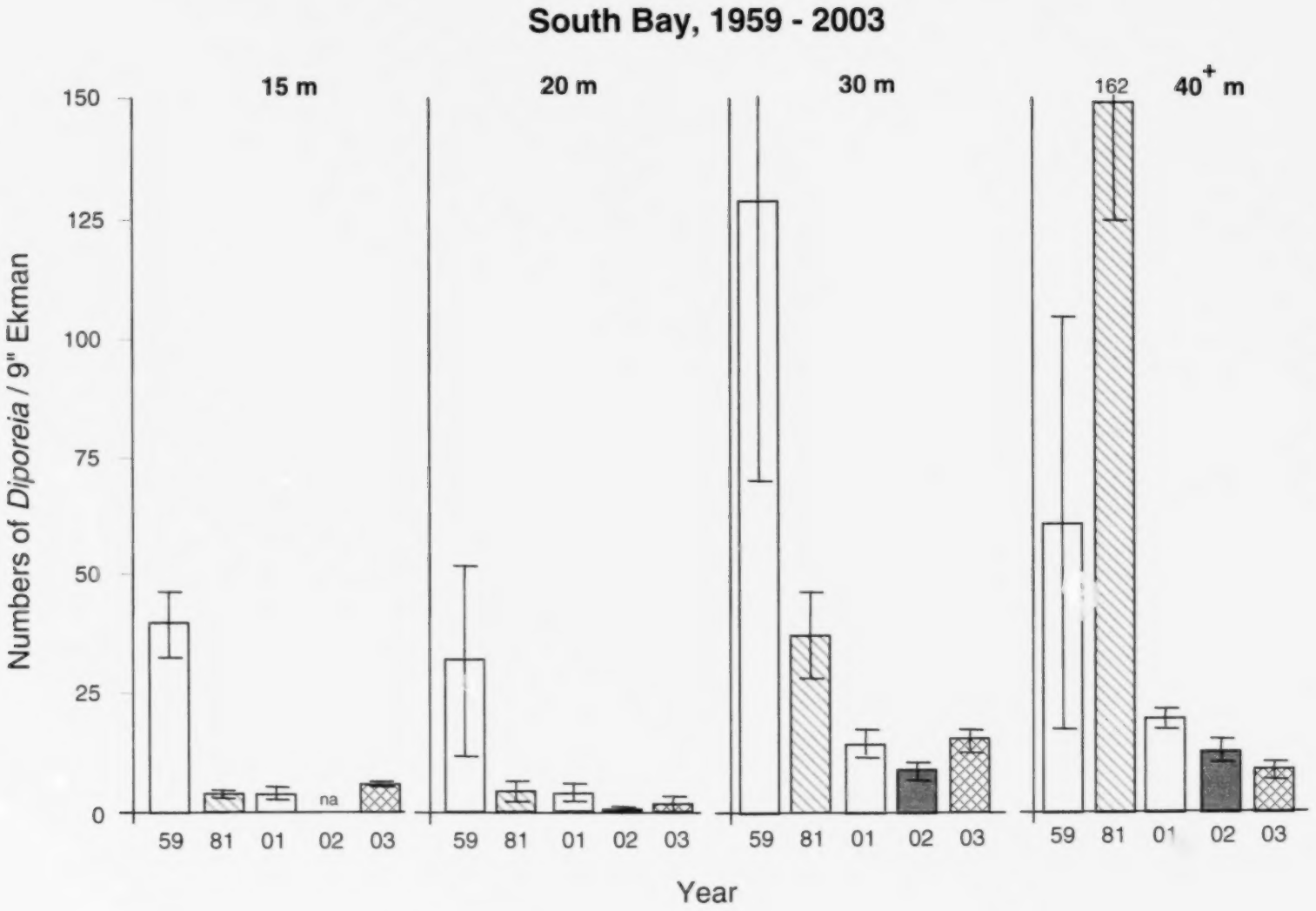

Figure 12. Density of *Diporeia* per 9" Ekman sample in South Bay, (Manitoulin) at various depths (m) in sample years 1959 through 2003.

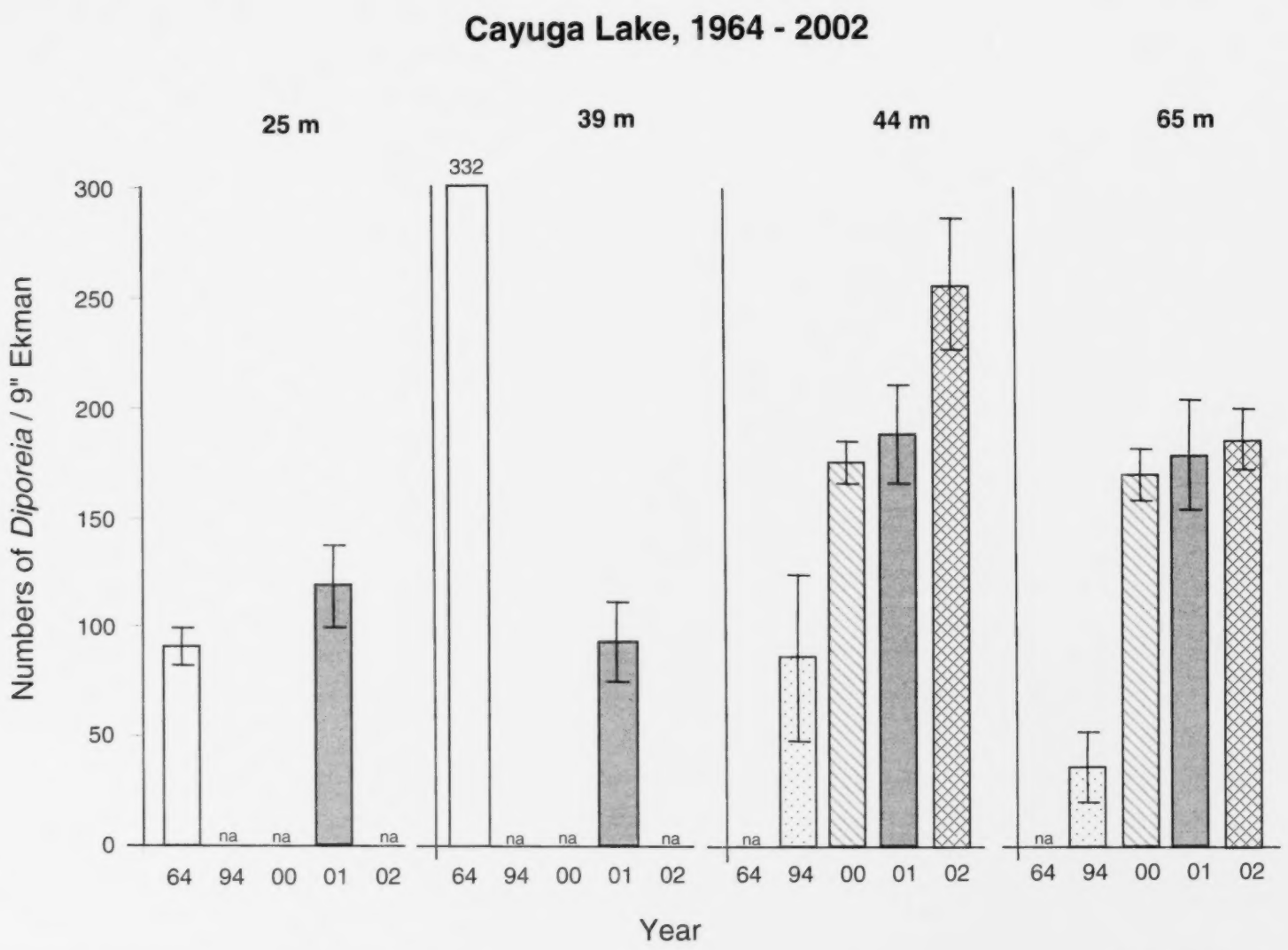

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Table 1. Lakes sampled for *Diporeia* spp., maximum lake or bay depth (z_m), years sampled (span), and year when *Dreissena* spp. were first found in the lakes. Lake abbreviations as used in the figures.

Lake	Abbreviations	Maximum Depth (z_m)	Sample Year Span		*Dreissena* Arrival
Batchawana Bay	Batc	45	1977	2001	no*?
Bernard	Bern	48	1972	2001	no
Blue Sea	Blue	54	1971	2001	no
Charleston	Char	91	1971	2001	2001*?
Champlain	Cham	123	1965	2001	1994
Cayuga	Cayu	130	1964	2002	1993
George	Geor	59	1982	2001	1999**
Mazinaw	Maz	145	1971	2001	no
Memphrémagog	Mem	107	1972	2001	no
Round	Rond	54	1971	2001	no
Seneca	Sen	170	1918	2001	1993
South Bay	Sbay	59	1959	2003	1997
Turkey	Turk	35	1980	2001	no
Winnipeg	Win	20	1969	2002	no

*? Not detected in sample area ** Currently being removed from lake

Table 2. Lake, sample site identifications, depth, and locations for sample years.

Lake	Site	Depth (m)	Latitude	Longitude	Year Sampled
New York State					
Lake Champlain	Main # 19	102.0	44° 28.590'	73° 17.864'	May 01
	Main # 19 NW	33.0	44° 27.310	73° 19.600	May 01
	Main # 19 W	20.0	44° 27.008	73° 19.833	May 01
	Shelburne #16	24.0	44° 25.695	73° 13.879	May 01
	Shelburne #16 W	20.0	44° 25.579	73° 14.500	May 01
	Mallets Bay # 25	33.0	44° 34.920	73° 16.870	May 01
	Mallets Bay # 24	21.0	44° 33.900	73° 12.500	May 01
	Mallets Bay #24 E	15.0	44° 33.546	73° 13.024	May 01
	Keeler Bay A	15.0	44° 40.549	73° 17.334	May 01
	Keeler Bay B	20.0	44° 40.486	73° 16.582	May 01
Lake George	Huck Island 40m	40.0	43° 33.395'	73° 37.605'	May 01
	Station #6	32.0	43° 32.129	73° 38.366	May 01
	Station #6 Inshore	20.0	43° 32.247	73° 38.380	May 01
	Station #1	15.0	43° 25.433	73° 42.202	May 01
	RR Station #15	32.0	43° 48.092	73° 27.722	May 01
Cayuga Lake	P3	43.8	42° 28.930'	76° 31.300'	Jn 00, Jul 01, Jl 02
	P4	65.0	42° 29.310	76° 31.410	Jn 00, Jul 01, Jl 02
	Meyer's Point	100.0	42° 31.953	76° 33.535	July 01
	Lev-25	25.0	42° 48.574	76° 43.623	July 01
	Lev-39	39.0	42° 47.281	76° 44.172	July 01
Seneca Lake	30m	30.2	42° 50.370'	76° 57.072'	Aug 01
	45m	45.5	42° 49.527	76° 57.993	Aug 01
	110m	110.0	42° 46.619	76° 57.035	Aug 01
Lac Memphrémagog					
	Spinney Point	12.0	45° 13.216'	72° 12.585'	Oct 01
	Spinney Pt.-A	19.9	45° 13.170	72° 12.364	Oct 01
	Spinney Pt.-B	20.7	45° 13.179	72° 12.293	Oct 01
	Green Pt. East	30.0	45° 13.692	72° 11.669	Oct 01
	Abbey Bay	40.5	45° 09.739	72° 15.265	Oct 01
	Sargent Bay	55.0	45° 08.756	72° 16.291	Oct 01
Blue Sea Lake	15m	15.0	46°14.621'	76° 02.216'	Sept 01
	20m	20.0	46° 14.588	76° 02.292	Sept 01
	30m	30.0	46° 14.311	76° 03.176	Sept 01
	40m	40.9	46° 14.255	76° 03.487	Sept 01
	50m	49.5	46° 14.122	76° 03.895	Sept 01
Round Lake					
	15m	15.7	'45° 39.106'	77° 32.376'	Sept 01
	20m	20.0	45° 39.239	77° 32.092	Sept 01
	30m	30.3	45° 39.333	77° 31.925	Sept 01
	40m	40.5	45° 39.378	77° 31.865	Sept 01
	50m	50.0	45° 39.389	77° 31.794	Sept 01

Continued on next page.

Table 2. Continued. Lake, sample site identifications, depth, and locations for sample years.

Lake	Site	Depth (m)	Latitude	Longitude	Year Sampled
Bernard Lake					
	# 15 m	16.0	45° 45.727'	79° 23.101'	June 01
	# 20 m	21.0	45° 45.674	79° 23.037	June 01
	# 25 m	25.0	45° 45.584	79° 22.957	June 01
	# 30 m	30.0	45° 45.551	79° 22.982	June 01
	# 40 m	40.0	45° 45.342	79° 22.892	June 01
	Deep Hole	45.0	45° 45.329	79° 22.739	June 01
Mazinaw Lake					
	10m	10.0	44° 57.472'	77° 14.326'	Sept 01
	20m	20.3	44° 57.290	77° 14.118	Sept 01
	30m	30.0	44° 57.165	77° 13.980	Sept 01
	40m	40.5	44° 56.946	77° 13.706	Sept 01
	60m	60.5	44° 56.658	77° 13.309	Sept 01
Charleston Lake					
	Town-10m	10.0	44° 34.158'	76° 00.108'	Oct 01
	Hen Isle-20m	20.0	44° 34.050	76° 00.139	Oct 01
	Hen Isle-30m	30.0	44° 33.897	76° 00.193	Oct 01
	Democrat Isle	40.0	44° 32.651	76° 01.207	Oct 01
	Repub. Isle-60m	60.0	44° 32.144	76° 01.263	Oct 01
	Repub. Isle-35m	30.2	44° 32.617	76° 01.245	Nov 02
	Repub. Isle-35m	38.3	44° 32.618	76° 01.246	Sept 05
	Crozier Isle-40 m	40.0	43° 31.335	76° 00.633	Jn.Aug.Sep.Nov 05
	Crozier Isle-40 m	42.0	43° 31.336	76° 00.635	July 06
Georgian Bay					
South Bay	# 5*	10.8	45° 40.500'	81° 50.160'	1959
	# 6	14.0	44° 35.723	81° 56.880	59, 81, Jn 01, Jl 03
	# 7	20.0	45° 35.889	81° 56.477	59, 81,Jn 01, Oct 02, Jl 03
	# 14	32.0	45° 39.654	81° 50.626	Jn 01, Oct 02, Jl 03
	# 8	36.0	45° 36.487	81° 55.009	59, 81, Jn 01, Oct 02, Jl 03
	# 22	42.5	45° 37.640	81° 53.280	July 2003
	# 25	37.0	45° 36.479	81° 53.896	Jn 01, Oct 02, Jl 03
	# 18	45.0	45° 37.953	81° 52.786	Jn 01, Oct 02, Jl 03
	# 28	37.0	45° 36.640	81° 54.230	July 2003
	# 9	55.0	45° 37.186	81° 53.007	59, 81, Jn 01, Oct 02, Jl 03
Lake Superior					
Batchawana Bay	L-5	32.0	46° 55.001'	84° 28.043'	July 01
	H-11	46.0	46° 52.812	84° 23.424	July 01
	J-4	25.1	46° 54.280	84° 28.883	July 01
	K-7	20.5	46° 54.499	84° 26.702	July 01
Big Turkey Lake	Site A	21.5	47° 02.925'	84° 25.061'	July 01
	Site B	26.8	47° 02.922	84° 25.274	July 01
	Site C	35.0	47° 02.909	84° 25.304	July 01

* The GPS data is based on the current location for this sample site.

Continued on next page.

Table 2. Continued. Lake, sample site identifications, depth, and locations for sample years.

Lake	Site	Depth (m)	Latitude	Longitude	Year Sampled
Winnipeg					
	# 5	9.8	50° 40.746'	96° 38.196'	1969, Aug 02
	# 12B	11.0	51° 08.046	96° 37.338	1969, Aug 02
	# 17	15.0	52° 48.499	97° 38.500	1969
	# 17	15.5	52° 53.040	97° 36.780	August 02
	# 20S	17.5	53° 13.482	97° 56.034	August 02
	# 20S	16.2	53° 13.482	97° 56.034	1969
	# 23C	16.4	53° 22.000	98° 33.250	1969
	# 23E	17.4	53° 16.000	98° 15.000	1969
	# 26	15.0	53° 19.500	99° 1.2498	1969
	# 26S	15.2	53° 24.774	98° 46.038	August 02
	# 27	7.3	53° 30.655	98° 48.546	1969
	# 54	12.5	52° 00.000	97° 02.466	August 02
	# 54	12.5	52° 0.0000	97° 2.5002	1969
	# 59	10.3	50° 41.832	96° 47.394	August 02
	# 59	11.0	50° 41.500	96° 44.502	1969
	# 60B	7.5	50° 38.064	96° 56.994	1969 + Aug 02

Table 3. Poisson regression model for all 14 lakes.

β	Estimate	Standard Error	MLE	(95% Confidence)
Intercept	3.4715	0.0120	–	–
Dreissena	-0.1628	0.0072	0.850	(0.8380 – 0.8620)
Depth	+0.0088	0.0003	1.009	(1.0088 – 1.0093)

Table 4. Statistical significance of the differences among pre-1992 and 2001 *Diporeia* density, ln(x+1) transformed, in individual lakes using ANOVA.

Variable	*df*	*F*	*p*	Sig or Not Sig	Increase/Decrease	Apperdix reference
Round Lake	1,18	53.82	<0.0001	***	Decrease	Appendix 9
Lake Champlain	7,98	49.88	<0.0001	***	Decrease	Appendix 1
South Bay	3,109	22.71	<0.0001	***	Decrease	Appendix 10
Lake Mazinaw	1,27	6.706	0.015	*	Decrease	Appendix 8
Seneca Lake	1,14	10.97	0.005	**	Increase	Appendix 3
Cayuga Lake	1,36	5.01	0.031	*	Increase	Appendix 3
Lake George	1,22	4.709	0.041	*	Increase	Appendix 2
Bernard Lake	1,23	4.071	0.055	N.S.	–	Appendix 7
Lac Blue Sea	1,18	1.958	0.179	N.S.	–	Appendix 5
Turkey Lake	1,18	1.159	0.296	N.S.	–	Appendix 11
Charleston lake	1,18	0.90	0.35	N.S.	–	Appendix 6
Lac Mephrémagog	1,46	0.17	0.68	N.S.	–	Appendix 4
Batchawana Bay	1,66	0.061	0.805	N.S.	–	Appendix 12
Lake Winnipeg	1,70	0.271	0.605	N.S.	–	Appendix 13

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; significant difference in *Dreissena* spp. densities between individual sites.

Table 5. Poisson regression model for lakes divided into those with and without *Dreissena* spp..

	Lakes without Mussels			Lakes with Mussels		
β	Estimate	Standard Error	*t*-value	Estimate	Standard Error	*t*-value
Intercept	3.8210	(0.0240)	161.425	3.5220	(0.0290)	121.243
Depth	-0.0082	(0.0006)	-12.937	0.0012	(0.0005)	2.243
Before/After 1992	0.0964	(0.0206)	4.668	-0.4370	(0.0185)	-23.654
95% conf. interval of MLE	1.058 to 1.147			0.623 to 0.670		

Table 6a. Benthic density (no. / 9" Ekman) at East site A (21m - Turkey Lake) sampled in 1980 and 2001.

Year	**1980**		**2001**	
Samples Analyzed	n = 22		n = 4	
Taxa	Ave.	S.E.	Ave.	S.E.
Oligochaeta	8.8	2.5	0	-
Ostracoda	0.0	0.0	0	-
Diporeia	14.8	3.8	61	25.4
Sphaeriidae	31.8	7.1	3	-
Chaoborus	0.0	0.0	0	-
Chironomini	10.0	2.2	3	-
Sergentia	0	0	0	-
Tanytarsini	95.0	17.6	3	-
Orthocladiinae	1.5	0.9	0	-
Tanypodinae	0.8	0.3	0	-
Total Chironomidae	**107.3**	**20.7**	**6**	**-**
Others	0.8	0.5	1	-
Total	**163.5**	**24.5**	**19**	**-**

Table 6b. Benthic density (no. / 9" Ekman) at Central site B (27m - Turkey Lake) sampled in 1980 and 2001.

Year	1980		2001	
Samples Analyzed	n = 5		n = 1	
Taxa	Ave.	S.E.	Ave.	S.E.
Oligochaeta	14.6	6.0	2	-
Ostracoda	0	0	0	-
Diporeia	9.0	8.3	79.5	6.3
Sphaeriidae	15.8	11.3	9	-
Chaoborus	0	0	0	-
Chironomini	37.2	2.2	43	-
Sergentia	0	0	-	-
Tanytarsini	10.6	6.6	9	-
Orthocladiinae	0.0	0.0	0	-
Tanypodinae	0.0	0.0	1	-
Total Chironomidae	**47.8**	**9.9**	**53**	**-**
Others	0.2	0.2	0	-
Total	**87.4**	**26.6**	**148**	**-**

Table 6c. Benthic density (no. / 9" Ponar) at site J4 (25m - Batchawana Bay) sampled in 1977 and 2001.

Year	**1977**		**2001**	
Samples Analyzed	n = 4		n = 1	
Taxa	Ave.	S.E.	Ave.	S.E.
Oligochaeta	10.5	2.0	63	-
Ostracoda	0.0	0.0	9	-
Diporeia	9.5	1.4	24	-
Sphaeriidae	11.0	1.4	42	-
Chaoborus	0	0	0	-
Chironomini	4.5	1.3	2.0	-
Sergentia	na	na	na	-
Tanytarsini	4.3	1.4	43	-
Orthocladiinae	3.5	1.5	2.0	-
Tanypodinae	0.5	0.5	4.0	-
Total Chironomidae	**12.8**	**3.2**	**51**	**-**
Others	2.0	1.2	1.0	-
Total	**62**	**-**	**192**	**-**

Table 6d. Benthic density (no. / 9" Ponar) at site L5 (32m - Batchawana Bay) sampled in 1977 and 2001.

Year	**1977**		**2001**	
Samples Analyzed	n = 8		n = 2	
Taxa	Ave.	S.E.	Ave.	S.E.
Oligochaeta	20.3	4.0	90.0	22.0
Ostracoda	1.5	1.5	11.0	7.0
Diporeia	31.7	4.2	54.5	7.5
Sphaeriidae	17.1	3.9	140.0	24.0
Chaoborus	0	0	0	0
Chironomini	7.0	1.9	4.2	3.0
Sergentia	na	na	na	na
Tanytarsini	2.5	1.3	110.5	39.5
Orthocladiinae	4.3	1.2	3.0	1.0
Tanypodinae	0.0	0.0	3.0	0.0
Total Chironomidae	**15.4**	**3.6**	**120.5**	**41.5**
Others	0.3	0.2	4.0	2.0
Total	**78.0**	**18.4**	**420.5**	**99.5**

Table 6e. Benthic density (no. / 6" Ekman) for Spinney Point (12-15m Lac Memphrémagog) sampled in 1972 and 2001.

Year	**1972**		**2001**	
Samples Analyzed	n = 6		n = 3	
Taxa	Ave.	S.E.	Ave.	S.E.
Oligochaeta	4.5	1.1	71.3	32.2
Ostracoda	3.2	0.7	9.3	3.3
Diporeia	21.2	10.5	15.0	5.8
Sphaeriidae	6.3	2.0	33.0	9.5
Chaoborus	8.0	3.7	1.7	0.9
Chironomini	9.0	2.2	4.3	1.7
Sergentia	3.7	2.0	0.3	0.3
Tanytarsini	18.4	4.0	4.7	1.4
Orthocladiinae	0.6	0.4	0.7	0.7
Tanypodinae	14.1	3.1	14.6	4.3
Total Chironomidae	**45.8**	**9.1**	**24.3**	**7.7**
Others	1.0	0.5	56.4	34.0
Total	**90.0**	**18.6**	**211.0**	**95.7**

Table 6f. Benthic density (no. / m^2) for Lake Winnipeg (whole lake averages) sampled in 1969 and 2002. 1969 data from Flannagan and Cobb (1994).

Year	**1969**		**2002**	
Total number of grabs	n = 687		n = 24	
Taxa	Ave.	S.E.	Ave.	S.E.
Total Ephemeroptera	60.0	-	384.5	197.0
Total Chironomidae	519.0	-	1650.8	448.6
Total Tricoptera	8.5	-	47.1	20.7
Total Oligochaete	485.2	-	3968.5	1815.3
Total Hirudinea	8.7	-	17.9	8.0
Macrocrustacea				
Mysis relicta	0.3	-	0	-
Caenestheriella setosa	2.5	-	26.9	26.9
Diporeia	1378.0	-	1541.6	1177.0
Gastropoda subtotal	na	-	84.2	32.1
Bivalvia subtotal	na	-	567.2	209.6
Total Mollusca	**545.0**	-	**651.5**	**223.5**
Total these taxa only	**3008.0**	**-**	**8288.8**	**43.0**
Sites analyzed	n = ?		n = 8	

Table 7. Summer regional temperature departures (°C) from 1948 - 2004 for the region of the Great Lakes and the St. Lawrence Valley from Environment Canada Website. Minus denotes cooler than normal temperatures.

Year	Departure	Year	Departure	Year	Departure	Year	Departure
1948	0.4	1963	-0.1	1978	-0.4	1993	0.5
1949	1.7	1964	-0.4	1979	-0.3	1994	0.1
1950	-0.5	1965	-1.3	1980	-0.3	1995	1.3
1951	-0.5	1966	0.6	1981	0.1	1996	0.0
1952	1.1	1967	0.2	1982	-1.3	1997	-0.2
1953	0.6	1968	-0.7	1983	1.1	1998	0.7
1954	-0.4	1969	0.0	1984	0.5	1999	1.2
1955	2.1	1970	0.4	1985	-0.9	2000	-0.6
1956	-0.7	1971	-0.3	1986	-0.8	2001	0.9
1957	-0.3	1972	-0.8	1987	0.9	2002	1.0
1958	-1.1	1973	1.5	1988	1.0	2003	0.5
1959	1.4	1974	0.1	1989	0.5	2004	-0.7
1960	-0.5	1975	1.0	1990	0.4		
1961	-0.1	1976	0.1	1991	1.2		
1962	-0.3	1977	-0.7	1992	-1.8		

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Appendix 2. Benthic sample sites in Lake George.

Appendix 3. Benthic sampling sites in Seneca and Cayuga Lakes.

Appendix 4. Benthic sites sample in Lac Memphrémagog.

Appendix 5. Benthic sites in Lac Blue Sea.

Appendix 6. Benthic sites in Charleston Lake.

Appendix 7. Benthic sites in Bernard Lake.

Appendix 8. Benthic sampling sites in Lake Mazinaw.

Appendix 9. Benthic sampling sites in Round Lake.

Appendix 10. Benthic sample sites in South Bay (Manitoulin Island - Georgian Bay).

Appendix 11. 1980 and 2001 benthic sites in Turkey Lake.

Appendix 12. 1977, 1978, and 2001 benthic sites in Batchawana Bay.

Appendix 13. 1969 and 2002 benthic sites sample in Lake Winnipeg.

Appendix 14a. Eastern Canadian and northern USA lakes.

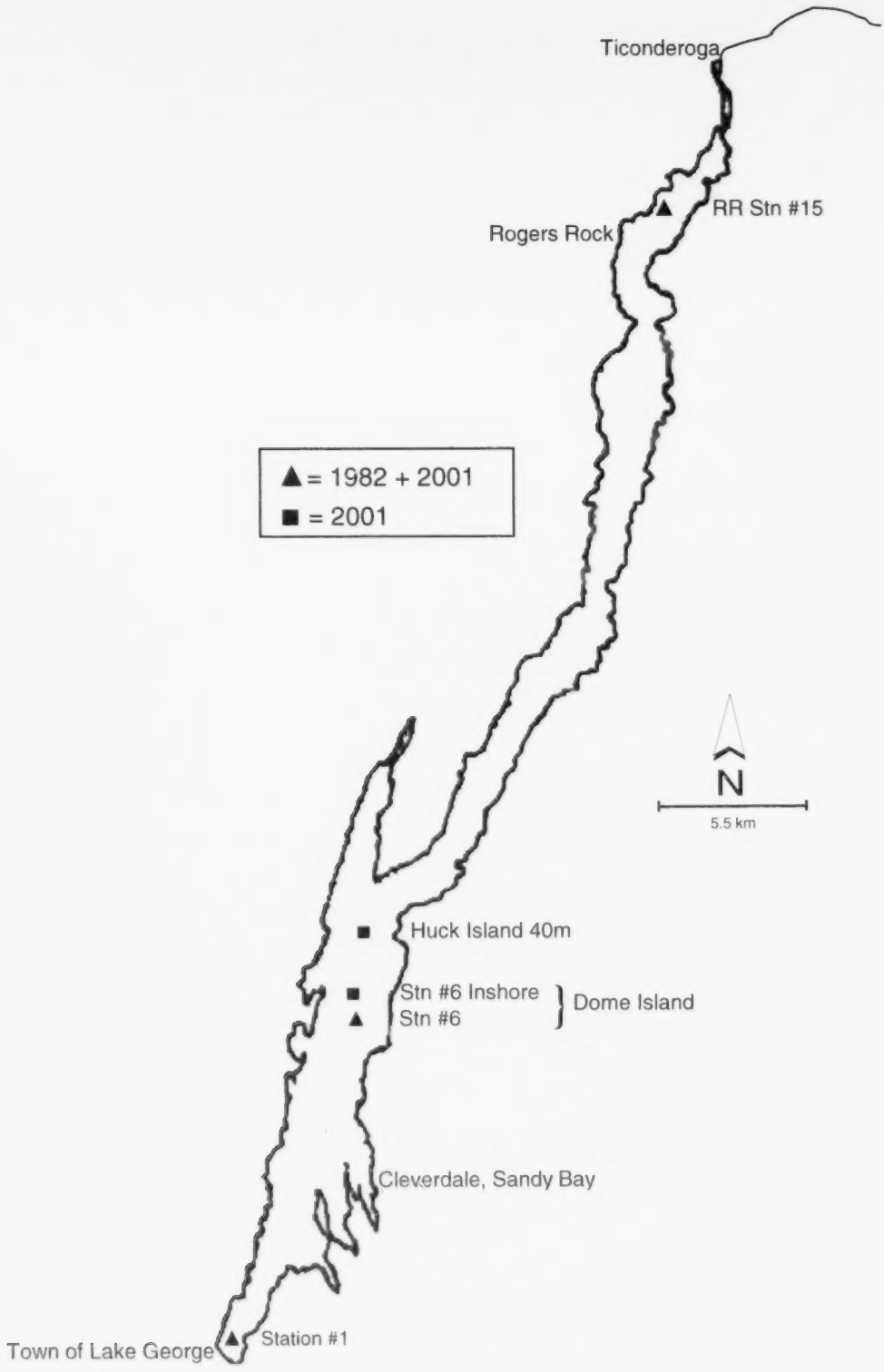
Appendix 14b. Central Ontario lakes.

Appendix 14c. Finger Lakes (New York State).

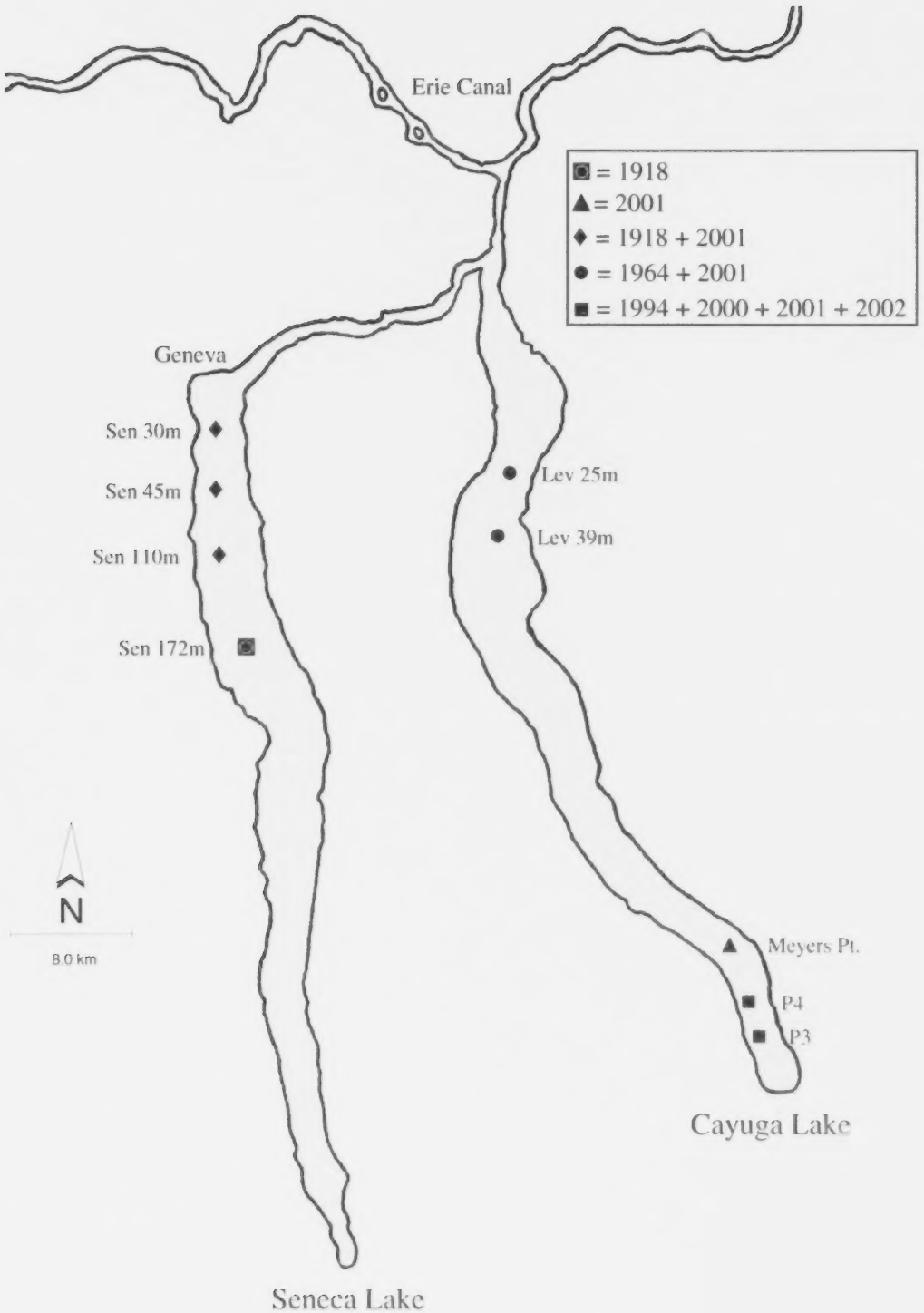
Appendix 14d. Northern lakes.

Appendix 15. Average Diporeia density (no./9" Ekman) for all sampled lakes in pre and post zebra mussels time periods.

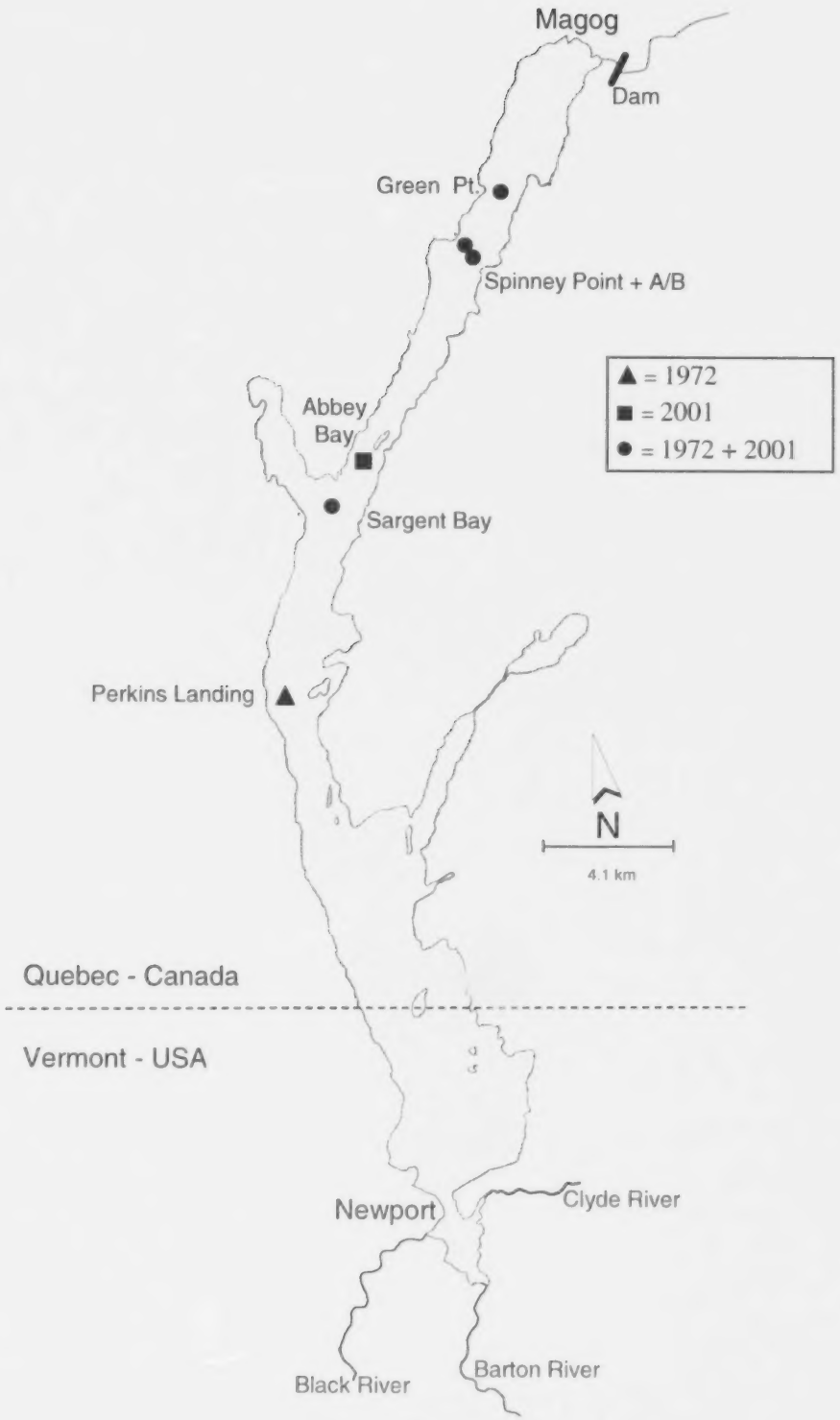
Appendix 1. Benthic sample sites in Lake Champlain for 2001 (circled) and previous years (for dates of previous years see appendix 14b).



Appendix 2. Benthic sample sites in Lake George.

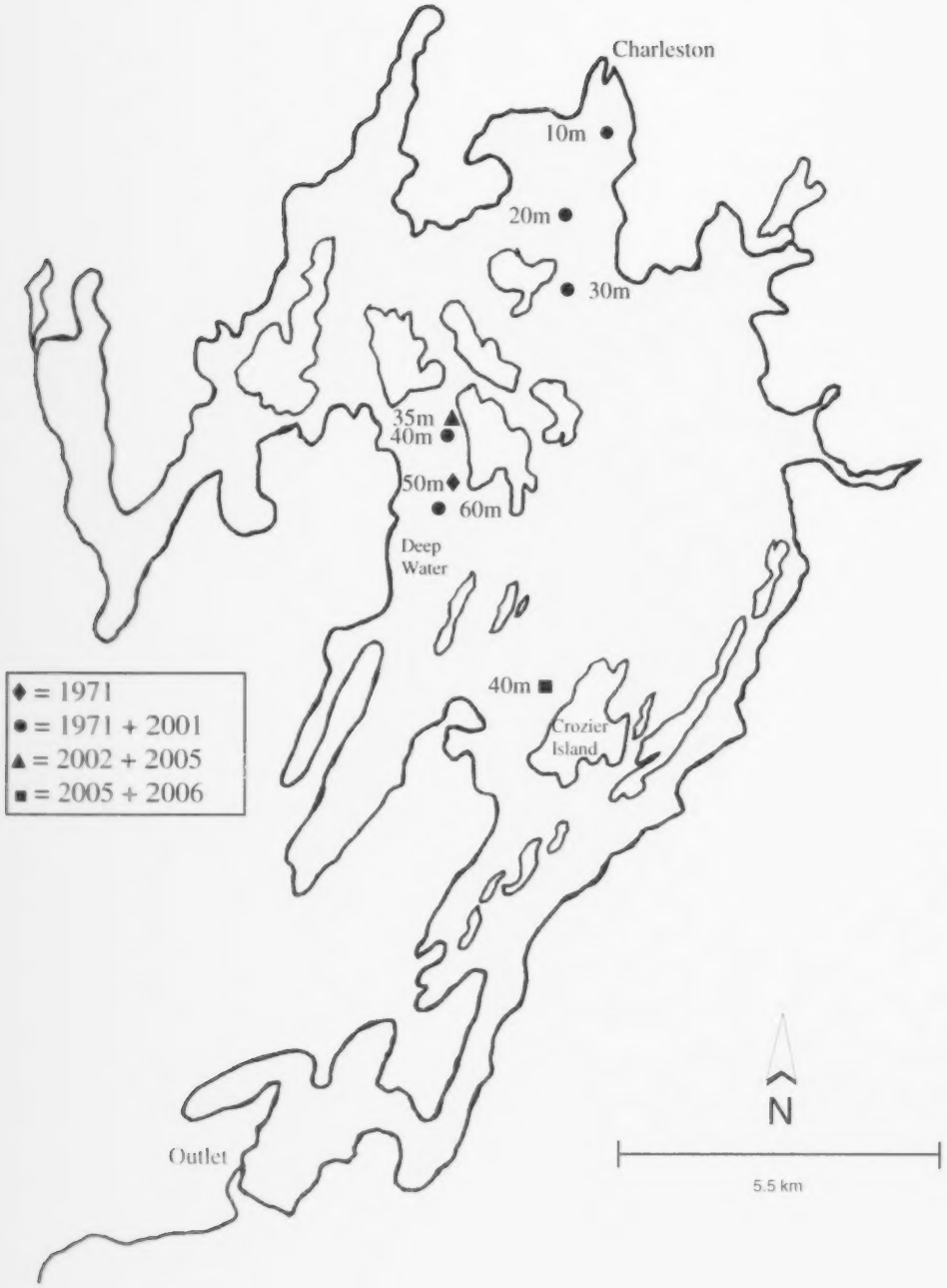


Appendix 3. Benthic sampling sites in Seneca and Cayuga Lakes.

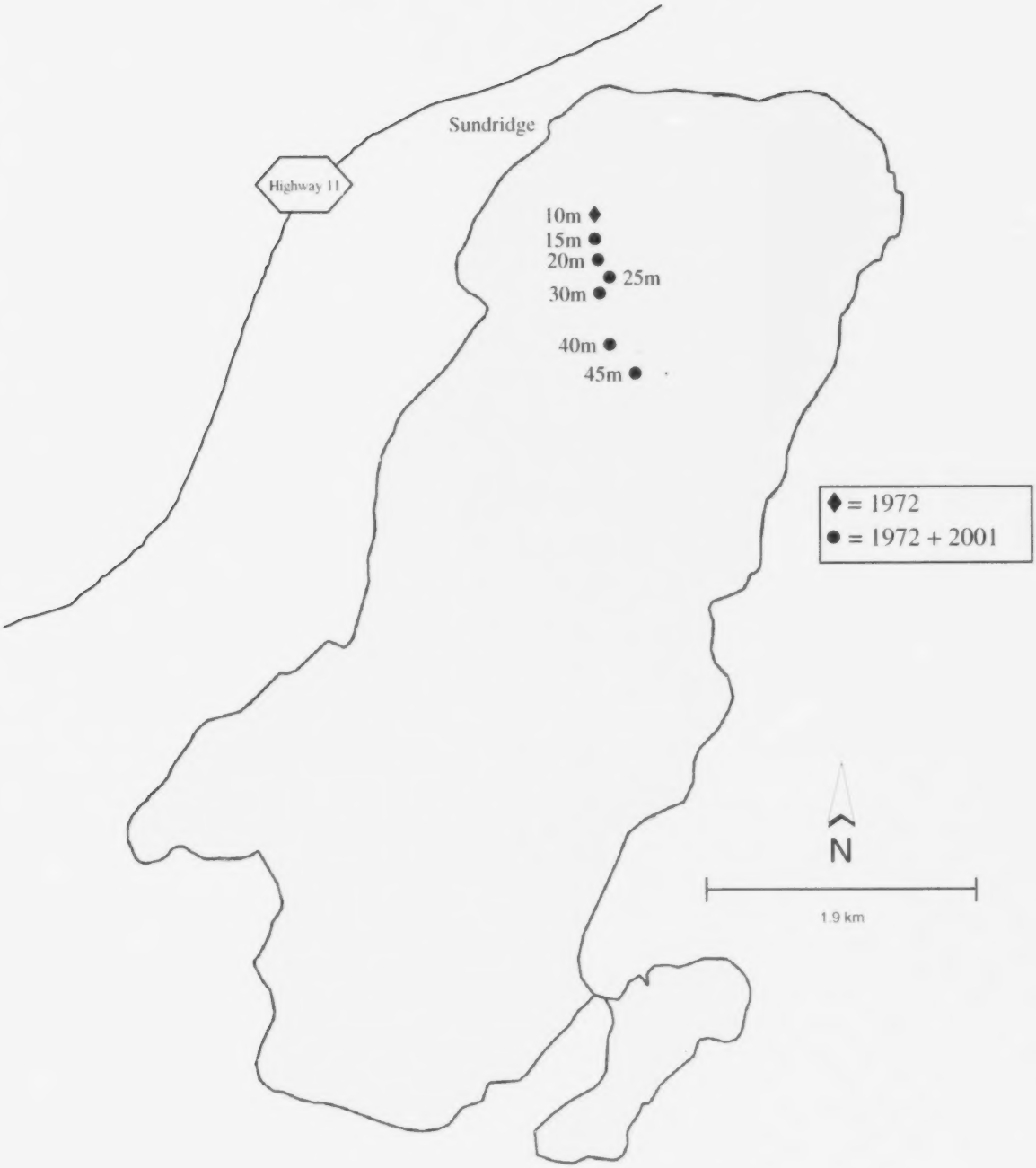


Appendix 4. Benthic sites sample in Lac Memphrémagog.

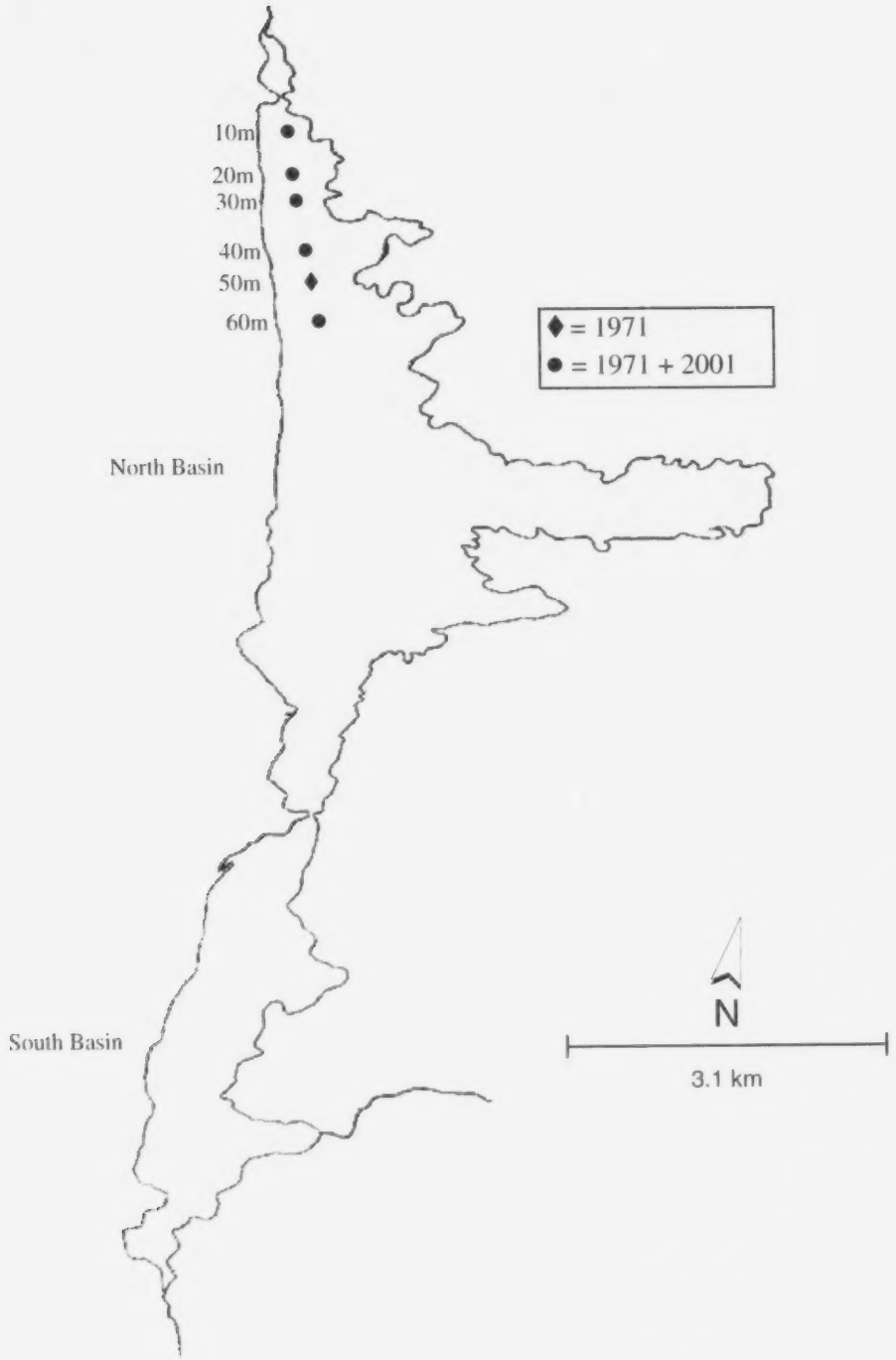
Appendix 5. Benthic sites in Lac Blue Sea.



Appendix 6. Benthic sites in Charleston Lake.

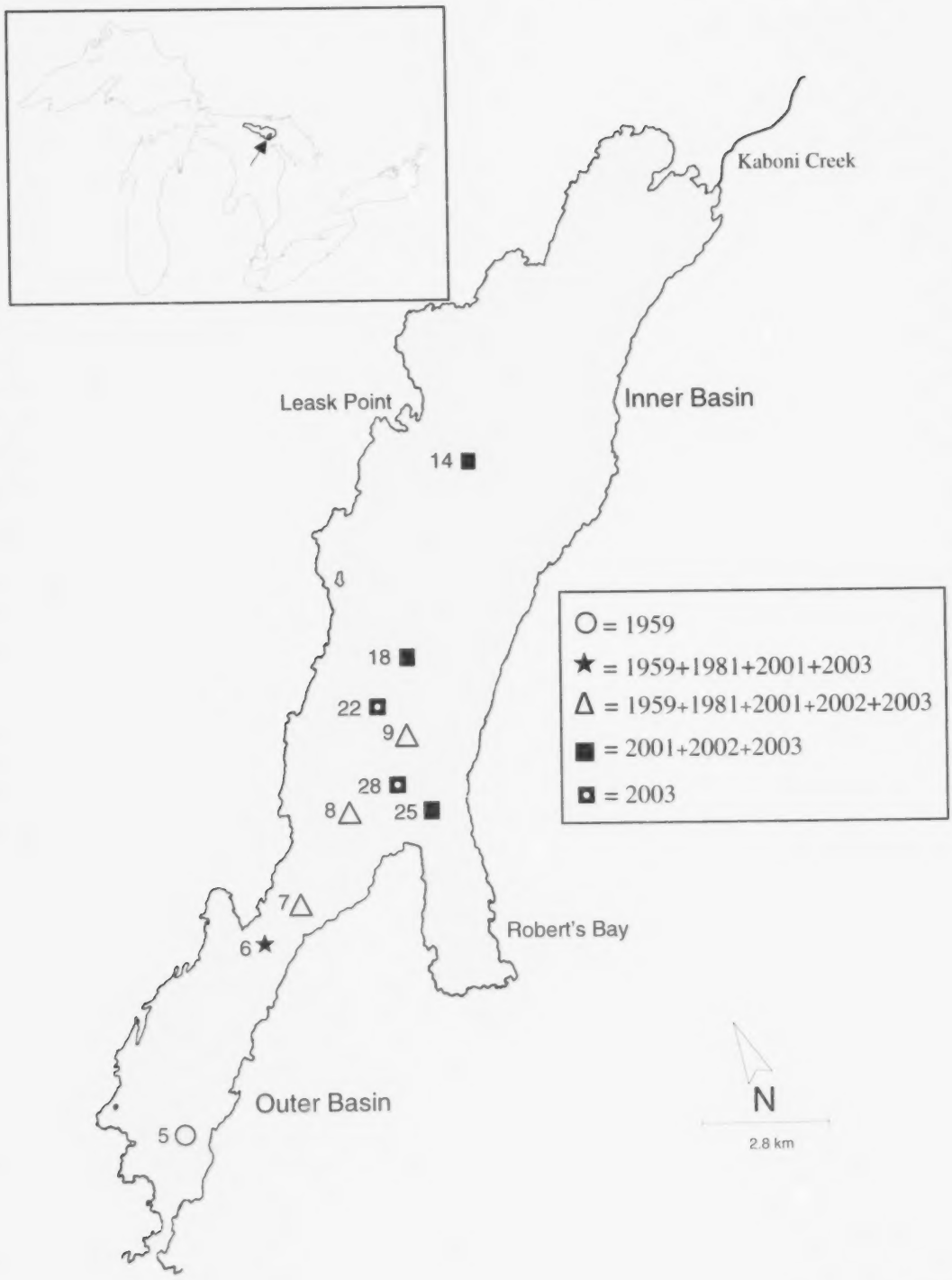


Appendix 7. Benthic sites in Bernard Lake.

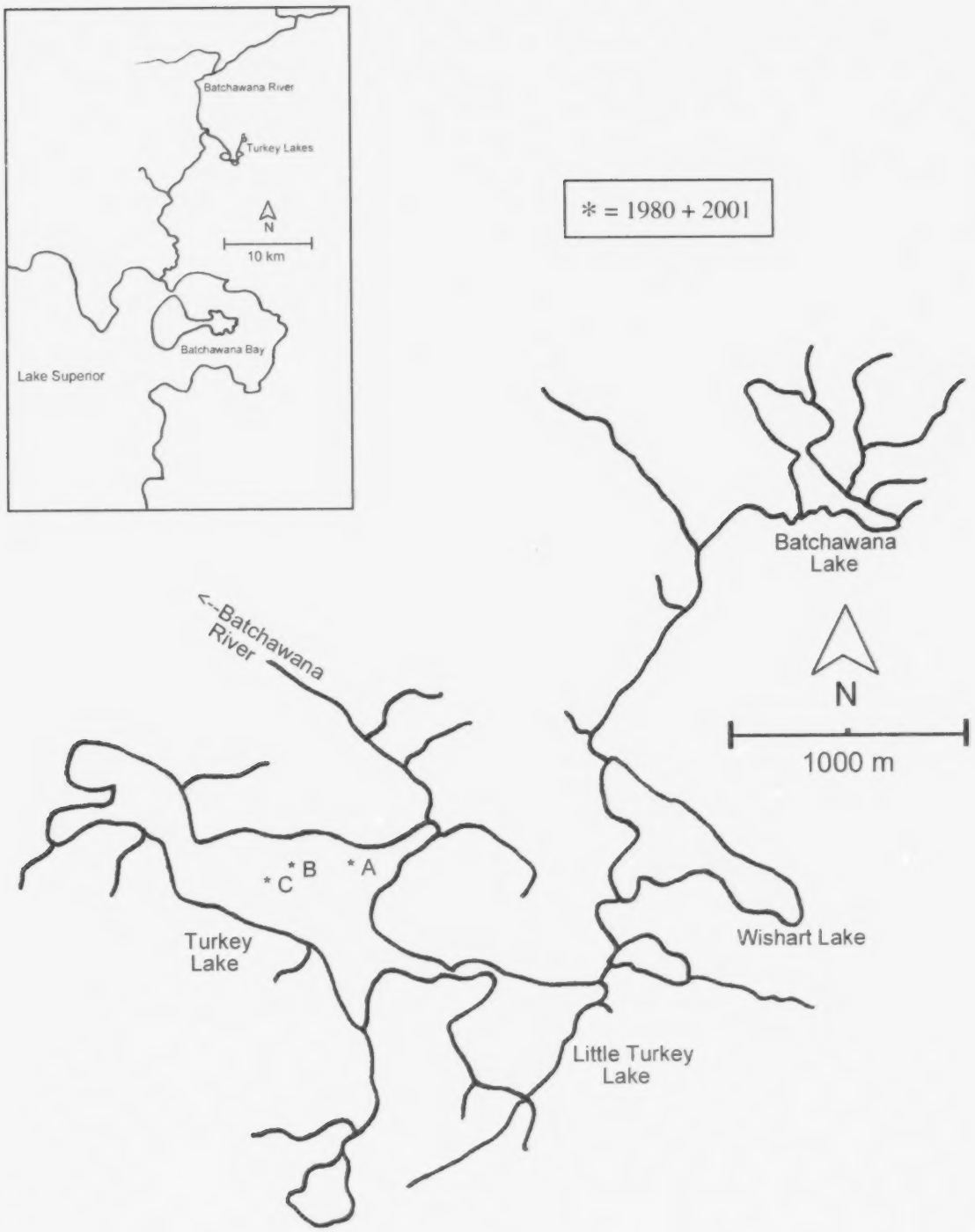


Appendix 8. Benthic sampling sites in Lake Mazinaw.

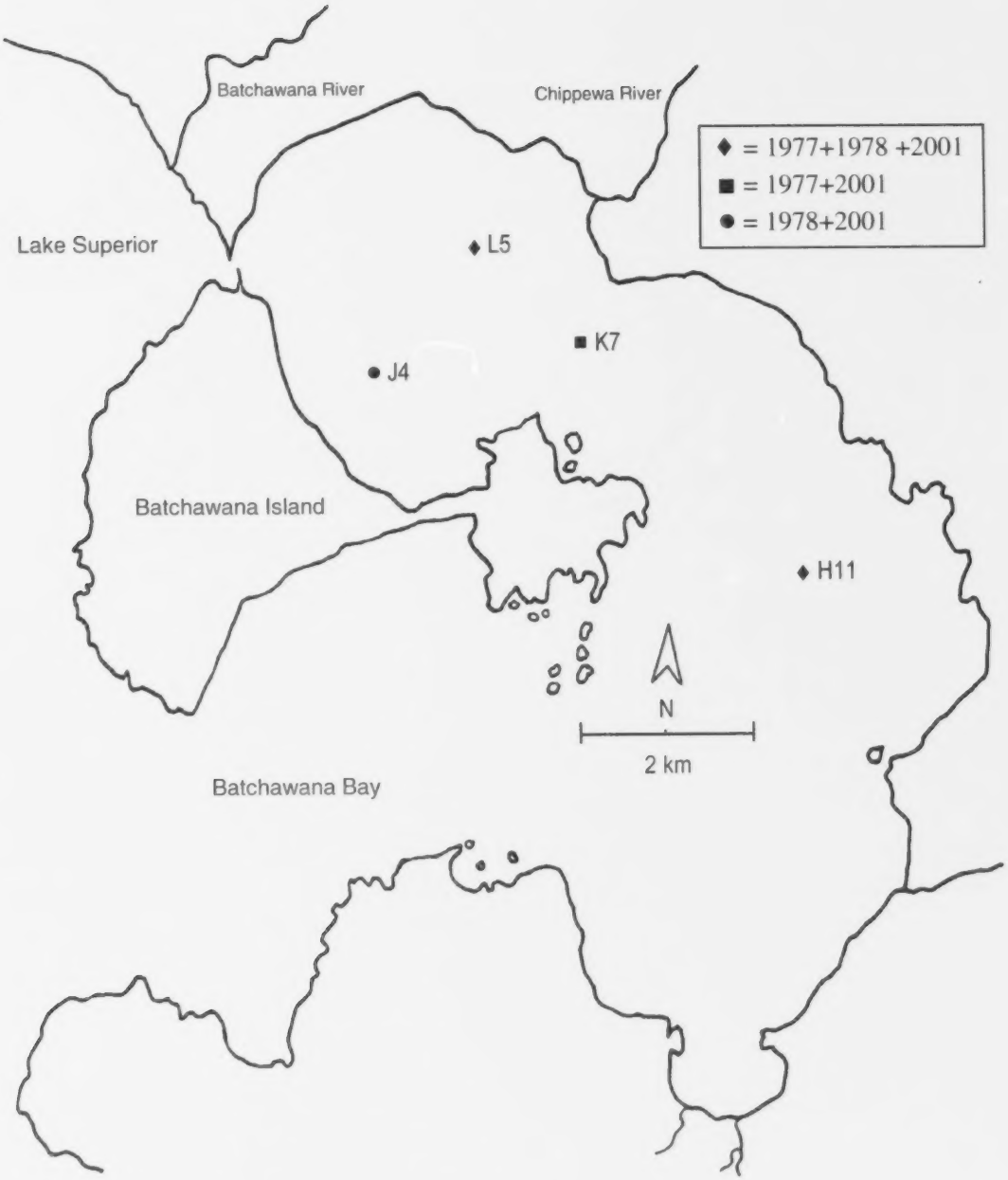
Appendix 9. Benthic sampling sites in Round Lake.



Appendix 10. Benthic sample sites in South Bay (Manitoulin Island - Georgian Bay).



Appendix 11. 1980 and 2001 benthic sites in Turkey Lake.



Appendix 12. 1977, 1978, and 2001 benthic sites in Batchawana Bay.

Appendix 13. 1969 and 2002 benthic sites sample in Lake Winnipeg.

Appendix 14a. Eastern Canadian and northern USA lakes. *Diporeia* spp. density (no./sample), biomass (g/sample wet weight), and zebra mussels presence (1 = present, 0 = absent) for sample years 1971-2002, na = not available.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Blue Sea								
	15 m	1971	9" Ekman	15	Ave	86	na	0
	20 m	1971	9" Ekman	20	Ave	140	na	0
	30 m	1971	9" Ekman	30	Ave	141	na	0
	40 m	1971	9" Ekman	40	Ave	235	na	0
	45 m	1971	9" Ekman	45	Ave	188	na	0
	50 m	1971	9" Ekman	50	Ave	161	na	0
	15 m	2001	9" Ekman	15	2	307	0.4635	0
	15 m	2001	9" Ekman	15	3	223	0.4033	0
	15 m	2001	9" Ekman	15	4	319	0.6118	0
	20 m	2001	9" Ekman	20	1	359	0.7283	0
	20 m	2001	9" Ekman	20	2	333	0.5629	0
	20 m	2001	9" Ekman	20	3	337	0.5411	0
	30 m	2001	9" Ekman	30	3	265	0.4460	0
	30 m	2001	9" Ekman	30	4	141	0.2915	0
	30 m	2001	9" Ekman	30	5	245	0.4339	0
	40 m	2001	9" Ekman	40.9	2	173	0.3097	0
	40 m	2001	9" Ekman	40.9	3	116	0.1967	0
	40 m	2001	9" Ekman	40.9	5	166	0.3217	0
	50 m	2001	9" Ekman	49.5	1	194	0.4240	0
	50 m	2001	9" Ekman	49.5	2	162	0.3316	0
	50 m	2001	9" Ekman	49.5	3	55	0.1040	0
Champlain								
	Shelburne Bay	1965	9" Ekman	16	1	12	na	0
	Shelburne Bay	1965	9" Ekman	19	0	4	na	0
	Keeler Bay #A	1969	9" Ekman	20	1	134	na	0
	Malletts Outer Bay #25	1988	9" Ekman	32	Ave	1	na	1
	Crown Point #4	1992	9" Ekman	10	Ave	0	na	0
	Malletts Inner Bay #24	1992	9" Ekman	21	1	1	na	0
	Malletts Inner Bay #24	1992	9" Ekman	21	2	1	na	0
	Cumberland #33	1992	9" Ekman	11	1	2	na	0
	Cumberland #34	1992	9" Ekman	11	2	0	na	0
	Cumberland #35	1992	9" Ekman	11	3	0	na	0
	Inland Sea #34	1992	9" Ekman	50	1	0	na	0
	Inland Sea #34	1992	9" Ekman	50	2	0	na	0
	Point Au Roche #36	1992	9" Ekman	50	Ave	0	na	0
	Point Au Roche #36	1992	9" Ekman	50	1	0	na	0
	Point Au Roche #36	1992	9" Ekman	50	2	0	na	0
	Point Au Roche #37	1992	9" Ekman	na	Ave	0	na	0
	St-Albans #40	1992	9" Ekman	7	1	0	na	0
	St-Albans #40	1992	9" Ekman	7	2	0	na	0

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Appendix 14a. Continued. Eastern Canadian and northern USA lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Champlain	St-Albans #40	1992	9" Ekman	7	3	0	na	0
	St-Albans #40	1992	9" Ekman	7	4	0	na	0
	St-Albans #40	1992	9" Ekman	7	5	0	na	0
	St-Albans #40	1992	9" Ekman	7	6	0	na	0
	St-Albans #48	1992	9" Ekman	7	1	0	na	0
	St-Albans #48	1992	9" Ekman	7	2	1	na	0
	Rouse's Pt. #49	1992	9" Ekman	6	1	1	na	0
	Rouse's Pt. #49	1992	9" Ekman	6	2	0	na	0
	Rouse's Pt. #49	1992	9" Ekman	6	3	0	na	0
	Malletts Outer Bay #26	1993	9" Ekman	32	1	0	na	0
	Malletts Outer Bay #27	1993	9" Ekman	32	2	0	na	0
	Cumberland #36	1993	9" Ekman	11	1	0	na	0
	Cumberland #37	1993	9" Ekman	11	2	0	na	0
	Inland Sea #34	1993	9" Ekman	50	1	0	na	0
	Inland Sea #34	1993	9" Ekman	50	2	0	na	0
	Inland Sea #34	1993	9" Ekman	50	3	0	na	0
	Inland Sea #34	1993	9" Ekman	50	4	0	na	0
	Inland Sea #34	1993	9" Ekman	50	5	0	na	0
	Inland Sea #34	1993	9" Ekman	50	6	0	na	0
	Point Au Roche #36	1993	9" Ekman	50	1	0	na	0
	Point Au Roche #36	1993	9" Ekman	50	2	0	na	0
	St-Albans #40	1993	9" Ekman	7	1	0	na	0
	St-Albans #40	1993	9" Ekman	7	2	0	na	0
	Crown Point #5	1994	9" Ekman	10	1	3	na	1
	Crown Point #6	1994	9" Ekman	10	2	0	na	1
	Crown Point #7	1994	9" Ekman	10	3	0	na	1
	Crown Point #8	1994	9" Ekman	10	4	0	na	1
	Crown Point #9	1994	9" Ekman	10	5	0	na	1
	Cole Bay #7	1994	9" Ekman	50	Ave	0	na	1
	Malletts Outer Bay #28	1994	9" Ekman	32	Ave	0	na	0
	Cumberland #38	1994	9" Ekman	11	1	0	na	0
	Cumberland #39	1994	9" Ekman	11	2	0	na	0
	Inland Sea #34	1994	9" Ekman	50	1	0	na	0
	Inland Sea #34	1994	9" Ekman	50	2	0	na	0
	Inland Sea #34	1994	9" Ekman	50	3	0	na	0
	Point Au Roche #36	1994	9" Ekman	50	Ave	0	na	0
	St-Albans #40	1994	9" Ekman	7	1	0	na	0
	St-Albans #40	1994	9" Ekman	7	2	0	na	0
	St-Albans #40	1994	9" Ekman	7	3	3	na	0
	St-Albans #40	1994	9" Ekman	7	4	0	na	0
	St-Albans #40	1994	9" Ekman	7	5	0	na	0
	St-Albans #40	1994	9" Ekman	7	6	1	na	0
	Crown Point #10	1995	9" Ekman	10	1	0	na	1
	Crown Point #11	1995	9" Ekman	10	2	0	na	1
	Crown Point #12	1995	9" Ekman	10	3	0	na	1

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Appendix 14a. Continued. Eastern Canadian and northern USA lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Champlain	Crown Point #13	1995	9" Ekman	10	4	0	na	1
	Main Lake #19	1995	9" Ekman	100	Ave	0	na	0
	Burlington Harb #21	1995	9" Ekman	15	1	0	na	1
	Burlington Harb #22	1995	9" Ekman	17	2	0	na	1
	Cumberland #40	1995	9" Ekman	11	Ave	0	na	0
	Inland Sea #34	1995	9" Ekman	50	Ave	0	na	0
	Point Au Roche #36	1995	9" Ekman	50	1	0	na	0
	St-Albans #40	1995	9" Ekman	7	1	0	na	0
	St-Albans #40	1995	9" Ekman	7	2	0	na	0
	St-Albans #40	1995	9" Ekman	7	3	0	na	0
	Crown Pt. #14	1996	9" Ekman	10	1	1	na	1
	Crown Pt. #15	1996	9" Ekman	10	2	0	na	1
	Main Lake #19	1996	9" Ekman	100	Ave	0	na	1
	A-Keeler Bay	2001	9" Ekman	15	1	0	0	1
	A-Keeler Bay	2001	9" Ekman	15	2	0	0	1
	A-Keeler Bay	2001	9" Ekman	15	5	0	0	1
	B-Keeler Bay	2001	9" Ekman	20	1	0	0	1
	B-Keeler Bay	2001	9" Ekman	20	2	0	0	1
	B-Keeler Bay	2001	9" Ekman	20	3	0	0	1
	Main Lake #19 W	2001	9" Ponar	20	2	0	0	1
	Main Lake #19 W	2001	9" Ponar	20	3	0	0	1
	Main Lake #19 W	2001	9" Ponar	20	4	0	0	1
	Main Lake #19 NW	2001	9" Ponar	33	1	0	0	1
	Main Lake #19 NW	2001	9" Ponar	33	2	0	0	1
	Main Lake #19 NW	2001	9" Ponar	33	4	0	0	1
	Main Lake #19 NW	2001	9" Ponar	33	5	0	0	1
	Main Lake #19	2001	9" Ponar	102	1	0	0	1
	Main Lake #19	2001	9" Ponar	102	2	0	0	1
	Main Lake #19	2001	9" Ponar	102	3	0	0	1
	Main Lake #19	2001	9" Ponar	102	4	0	0	1
	Malletts Inner Bay 24 E	2001	9" Ekman	15	2	0	0	1
	Malletts Inner Bay 24 E	2001	9" Ekman	15	4	0	0	1
	Malletts Inner Bay 24 E	2001	9" Ekman	15	5	0	0	1
	Malletts Inner Bay #24	2001	9" Ekman	21	1	0	0	1
	Malletts Inner Bay #24	2001	9" Ekman	21	4	0	0	1
	Malletts Inner Bay #24	2001	9" Ekman	21	5	0	0	1
	Malletts Outer Bay #25	2001	9" Ekman	33	1	0	0	1
	Malletts Outer Bay #25	2001	9" Ekman	33	4	0	0	1
	Malletts Outer Bay #25	2001	9" Ekman	33	5	0	0	1
	Shelburne Bay #16 W	2001	9" Ponar	20	2	0	0	1
	Shelburne Bay #16 W	2001	9" Ponar	20	3	0	0	1
	Shelburne Bay #16 W	2001	9" Ponar	20	5	0	0	1
	Shelburne Bay #16	2001	9" Ponar	24	1	0	0	1
	Shelburne Bay #16	2001	9" Ponar	24	5	0	0	1
	Shelburne Bay #16	2001	9" Ponar	24	3	0	0	1

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Appendix 14a. Continued. Eastern Canadian and northern USA lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
George								
	Station #1	1982	6" Ekman	15	Ave	24.9	na	0
	Station #6	1982	6" Ekman	32	Ave	12.4	na	0
	RR Station #15	1982	6" Ekman	32	Ave	6.7	na	0
	Station #1	2001	6" Ekman	15	1	38	0.0120	1
	Station #1	2001	6" Ekman	15	2	3	0.0064	1
	Station #1	2001	6" Ekman	15	4	51	0.0424	1
	Station #6 Inshore	2001	6" Ekman	20	2	47	0.0350	1
	Station #6 Inshore	2001	6" Ekman	20	4	74	0.0386	1
	Station #6 Inshore	2001	6" Ekman	20	5	66	0.0435	1
	Station #6	2001	6" Ekman	32	3	50	0.0560	1
	Station #6	2001	6" Ekman	32	4	44	0.0569	1
	Station #6	2001	6" Ekman	32	5	43	0.0339	1
	RR Station #15	2001	6" Ekman	32	1	109	0.0737	1
	RR Station #15	2001	6" Ekman	32	3	14	0.0155	1
	RR Station #15	2001	6" Ekman	32	5	4	0.0068	1
	Huck Island 40m	2001	6" Ekman	40	1	10	0.0220	1
	Huck Island 40m	2001	6" Ekman	40	4	44	0.0392	1
	Huck Island 40m	2001	6" Ekman	40	5	16	0.0361	1
Memphrémagog								
	Spinney Point	1972	6" Ekman	12	1	5	0.0089	0
	Spinney Point	1972	6" Ekman	12	2	46	0.1022	0
	Spinney Point	1972	6" Ekman	12	3	10	0.0234	0
	Spinney Point	1972	6" Ekman	15	4	61	0.1201	0
	Spinney Point	1972	6" Ekman	12	5	4	0.0145	0
	Spinney Point	1972	6" Ekman	12	6	1	0.0038	0
	Spinney Point	1972	6" Ekman	20	1	0	0.0000	0
	Spinney Point	1972	6" Ekman	20	2	0	0.0000	0
	Spinney Point	1972	6" Ekman	20	3	0	0.0000	0
	Spinney Point	1972	6" Ekman	20	4	49	0.0378	0
	Spinney Point	1972	6" Ekman	20	5	1	0.0074	0
	Spinney Point	1972	6" Ekman	20	6	47	0.0570	0
	Spinney Point	1972	6" Ekman	20	7	16	0.0354	0
	Spinney Point	1972	6" Ekman	20	8	5	0.0110	0
	Spinney Point	1972	6" Ekman	20	9	4	0.0065	0
	Spinney Point	1972	6" Ekman	20	10	5	0.0287	0
	Spinney Point	1972	6" Ekman	20	11	14	0.0283	0
	Spinney Point	1972	6" Ekman	20	12	0	0.0000	0
	Spinney Point	1972	6" Ekman	20	13	11	0.0257	0
	Spinney Point	1972	6" Ekman	17	14	26	0.0623	0
	Green Point	1972	6" Ekman	30	1	0	0.0000	0
	Green Point	1972	6" Ekman	30	2	0	0.0000	0
	Green Point	1972	6" Ekman	30	3	0	0.0000	0

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Appendix 14a. Continued. Eastern Canadian and American Lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Memphrémagog								
	Sargent Bay	1972	6" Ekman	56	1	19	0.0526	0
	Sargent Bay	1972	6" Ekman	56	2	11	0.0331	0
	Perkins Lnd.	1972	6" Ekman	57	3	6	0.0169	0
	Perkins Lnd.	1972	6" Ekman	57	4	7	0.0210	0
	Spinney Point	2001	6" Ekman	12	1	13	0.0278	0
	Spinney Point	2001	6" Ekman	12	2	6	0.0136	0
	Spinney Point	2001	6" Ekman	12	3	13	0.0293	0
	Spinney Point	2001	6" Ekman	12	4	26	0.0876	0
	Spinney Point	2001	6" Ekman	12	5	7	0.0132	0
	Spinney Pt.-A	2001	6" Ekman	19.9	1	24	0.0911	0
	Spinney Pt.-B	2001	6" Ekman	20.7	2	5	0.0144	0
	Spinney Pt.-B	2001	6" Ekman	20.7	3	7	0.0194	0
	Spinney Pt.-B	2001	6" Ekman	20.7	5	7	0.0132	0
	Green Point	2001	6" Ekman	30	2	0	0	0
	Green Point	2001	6" Ekman	30	3	1	0.0007	0
	Green Point	2001	6" Ekman	30	4	0	0	0
	Green Point	2001	6" Ekman	30	5	0	0	0
	Abbey Bay	2001	6" Ekman	40.5	1	19	0.0644	0
	Abbey Bay	2001	6" Ekman	40.5	2	10	0.0316	0
	Abbey Bay	2001	6" Ekman	40.5	3	26	0.0868	0
	Abbey Bay	2001	6" Ekman	40.5	4	5	0.0071	0
	Sargent Bay	2001	6" Ekman	55	2	25	0.0599	0
	Sargent Bay	2001	6" Ekman	55	3	7	0.0347	0
	Sargent Bay	2001	6" Ekman	55	4	3	0.0048	0
	Sargent Bay	2001	6" Ekman	55	5	4	0.0122	0

Appendix 14b. Central Ontario lakes. *Diporeia* spp. density (no./sample), biomass (g/sample wet weight), and zebra mussels presence (1 = present, 0 = absent) for sample years 1971-2005, na = not available.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Bernard								
	10 m	1972	9" Ekman	10	Ave	2.5	na	0
	15 m	1972	9" Ekman	15	Ave	38.0	na	0
	20 m	1972	9" Ekman	20	Ave	42.5	na	0
	25 m	1972	9" Ekman	25	Ave	58.5	na	0
	30 m	1972	9" Ekman	30	Ave	10.5	na	0
	40 m	1972	9" Ekman	40	Ave	24.5	na	0
	Deephole	1972	9" Ekman	45	Ave	0	na	0
	15 m	2001	9" Ekman	15	1	124	0.0650	0
	15 m	2001	9" Ekman	15	2	69	0.0391	0
	15 m	2001	9" Ekman	15	3	0	0.0000	0
	15 m	2001	9" Ekman	15	5	140	0.1063	0
	20 m	2001	9" Ekman	20	1	110	0.1131	0
	20 m	2001	9" Ekman	20	2	90	0.1395	0
	20 m	2001	9" Ekman	20	3	65	0.1007	0
	25 m	2001	9" Ekman	25	1	191	0.1631	0
	25 m	2001	9" Ekman	25	3	114	0.2862	0
	25 m	2001	9" Ekman	25	4	88	0.2229	0
	30 m	2001	9" Ekman	30	1	91	0.2731	0
	30 m	2001	9" Ekman	30	2	65	0.2798	0
	30 m	2001	9" Ekman	30	3	143	0.2800	0
	40 m	2001	9" Ekman	40	1	45	0.1366	0
	40 m	2001	9" Ekman	40	2	28	0.1260	0
	40 m	2001	9" Ekman	40	3	76	0.2559	0
	Deephole	2001	9" Ekman	45	1	0	0.0000	0
	Deephole	2001	9" Ekman	45	2	0	0.0000	0
	Deephole	2001	9" Ekman	45	3	0	0.0000	0
Charleston								
	10 m	1971	9" Ekman	10	1	120	na	0
	20 m	1971	9" Ekman	20	1	232	na	0
	30 m	1971	9" Ekman	30	1	263	na	0
	40 m	1971	9" Ekman	40	1	231	na	0
	50 m	1971	9" Ekman	50	1	96	na	0
	60 m	1971	9" Ekman	60	1	134	na	0
	Town	2001	9" Ekman	10	2	3	0.0062	0
	Town	2001	9" Ekman	10	3	5	0.0110	0
	Town	2001	9" Ekman	10	4	3	0.0057	0
	Hen Island	2001	9" Ekman	20	1	478	0.6041	0
	Hen Island	2001	9" Ekman	20	2	499	0.5903	0
	Hen Island	2001	9" Ekman	20	3	622	0.7020	0
	Hen Island	2001	9" Ekman	30	2	55	0.0930	0
	Hen Island	2001	9" Ekman	30	3	93	0.2263	0
	Hen Island	2001	9" Ekman	30	4	119	0.2626	0

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Appendix 14b. Central Ontario lakes continued.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Charleston								
	Democrat Isle	2001	9" Ekman	40	1	110	0.2035	0
	Democrat Isle	2001	9" Ekman	40	2	235	0.5467	0
	Democrat Isle	2001	9" Ekman	40	3	216	0.9158	0
	Republican Isle	2001	9" Ekman	60	1	157	0.5014	0
	Republican Isle	2001	9" Ekman	60	2	177	0.4101	0
	Republican Isle	2001	9" Ekman	60	4	152	0.2954	0
	Democrat-35m	2002	9" Ekman	30.2	1	166"	na	0
	Democrat-35m	2002	9" Ekman	30.2	2	375"	na	0
	Democrat-35m	2002	9" Ekman	30.2	3	503"	na	0
	Democrat-35m	2005	9" Ekman	38.3	1	147††	na	0
	Democrat-35m	2005	9" Ekman	38.3	2	67††	na	0
	Democrat-35m	2005	9" Ekman	38.3	3	99††	na	0
	Crozier Isle-40m	2005	9" Ekman	42.3	1	143"	na	0
	Crozier Isle-40m	2005	9" Ekman	42.3	2	61"	na	0
	Crozier Isle-40m	2005	9" Ekman	42.3	3	58"	na	0
	Crozier Isle-40m	2005	9" Ekman	42.5	1	182††	na	0
	Crozier Isle-40m	2005	9" Ekman	42.5	2	163††	na	0
	Crozier Isle-40m	2005	9" Ekman	42.5	3	111††	na	0
	Crozier Isle-40m	2005	9" Ekman	43.1	1	275*	na	1
	Crozier Isle-40m	2005	9" Ekman	43.1	2	119*	na	0
	Crozier Isle-40m	2005	9" Ekman	45	1	233**	na	0
	Crozier Isle-40m	2005	9" Ekman	45	2	152**	na	0
	Crozier Isle-40m	2005	9" Ekman	45	3	180**	na	0
	Crozier Isle-40m	2006	9" Ekman	42	1	133†	na	0
	Crozier Isle-40m	2006	9" Ekman	42	2	160†	na	0
	Crozier Isle-40m	2006	9" Ekman	42	3	108†	na	0
	*June †July **Aug ††Sept "Nov							
Mazinaw								
	10 m	1971	9" Ekman	10	Ave	14	na	0
	20 m	1971	9" Ekman	20	Ave	21	na	0
	30 m	1971	9" Ekman	30	Ave	20	na	0
	40 m	1971	9" Ekman	40	Ave	25	na	0
	50 m	1971	9" Ekman	50	Ave	23	na	0
	60 m	1971	9" Ekman	60	Ave	15	na	0
	10 m	2001	9" Ekman	10	1	3	0.0044	0
	10 m	2001	9" Ekman	10	2	4	0.0089	0
	10 m	2001	9" Ekman	10	3	1	0.0034	0
	10 m	2001	9" Ekman	10	5	1	0.0012	0
	20 m	2001	9" Ekman	20	1	0	0.0000	0
	20 m	2001	9" Ekman	20	2	0	0.0000	0
	20 m	2001	9" Ekman	20	3	2	0.0067	0
	20 m	2001	9" Ekman	20	4	0	0.0000	0
	20 m	2001	9" Ekman	20	5	2	0.0056	0

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Appendix 14b. Central Ontario lakes continued.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence
Mazinaw								
	30 m	2001	9" Ekman	30	1	19	0.0641	0
	30 m	2001	9" Ekman	30	2	18	0.0274	0
	30 m	2001	9" Ekman	30	3	25	0.0191	0
	30 m	2001	9" Ekman	30	5	23	0.0233	0
	40 m	2001	9" Ekman	40	1	25	0.0303	0
	40 m	2001	9" Ekman	40	2	0	0.0000	0
	40 m	2001	9" Ekman	40	3	11	0.0070	0
	40 m	2001	9" Ekman	40	4	23	14.000	0
	40 m	2001	9" Ekman	40	5	10	0.0031	0
	60 m	2001	9" Ekman	60	1	16	0.0202	0
	60 m	2001	9" Ekman	60	2	13	0.0174	0
	60 m	2001	9" Ekman	60	3	5	0.0101	0
	60 m	2001	9" Ekman	60	4	16	0.0308	0
	60 m	2001	9" Ekman	60	5	3	0.0006	0
Round								
	15 m	1971	9" Ekman	15	Ave	27	na	0
	20 m	1971	9" Ekman	20	Ave	22	na	0
	30 m	1971	9" Ekman	30	Ave	22	na	0
	40 m	1971	9" Ekman	40	Ave	33	na	0
	50 m	1971	9" Ekman	50	Ave	45	na	0
	15 m	2001	9" Ekman	15	1	12	0.0163	0
	15 m	2001	9" Ekman	15	2	9	0.0154	0
	15 m	2001	9" Ekman	15	5	8	0.0196	0
	20 m	2001	9" Ekman	20	1	6	0.0168	0
	20 m	2001	9" Ekman	20	2	12	0.0310	0
	20 m	2001	9" Ekman	20	4	6	0.0198	0
	30 m	2001	9" Ekman	30	1	16	0.0362	0
	30 m	2001	9" Ekman	30	3	5	0.0113	0
	30 m	2001	9" Ekman	30	4	6	0.0161	0
	40 m	2001	9" Ekman	40	2	1	0.0089	0
	40 m	2001	9" Ekman	40	3	0	0.0000	0
	40 m	2001	9" Ekman	40	5	2	0.0056	0
	50 m	2001	9" Ekman	50	2	0	0.0000	0
	50 m	2001	9" Ekman	50	3	0	0.0000	0
	50 m	2001	9" Ekman	50	4	0	0.0000	0

Appendix 14c. Finger Lakes (New York State). *Diporeia* spp. density (no./sample), biomass (g/sample wet weight), and zebra mussels presence (1 = present, 0 = absent) for sample years 1918-2001, zebra mussel density (no./sample), biomass (g/sample wet weight), na = not available.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia*		Zebra Mussel		
						Density	Biomass	Presence	Density	Biomass
Cayuga										
	Lev-25	1964	9" Ekman	25	1	88	na	0	na	na
	Lev-25	1964	9" Ekman	25	2	77	na	0	na	na
	Lev-25	1964	9" Ekman	25	3	107	na	0	na	na
	Lev-39	1964	9" Ekman	39	1	334	na	0	na	na
	Lev-39	1964	9" Ekman	39	2	317	na	0	na	na
	Lev-39	1964	9" Ekman	39	3	346	na	0	na	na
	P3	1994	9" Ekman	44	1	158	na	0	na	na
	P3	1994	9" Ekman	44	2	68	na	0	na	na
	P3	1994	9" Ekman	44	3	32	na	0	na	na
	P4	1994	9" Ekman	65	1	68	na	0	na	na
	P4	1994	9" Ekman	65	2	27	na	0	na	na
	P4	1994	9" Ekman	65	3	14	na	0	na	na
	P3	2000	9" Ekman	44	1	157	0.1469	1	0	0
	P3	2000	9" Ekman	44	2	148	0.2059	1	144	13.2399
	P3	2000	9" Ekman	44	3	197	0.2861	1	68	4.1570
	P3	2000	9" Ekman	44	4	181	0.2481	1	78	8.2729
	P3	2000	9" Ekman	44	5	194	0.3076	1	73	6.3333
	P4	2000	9" Ekman	65	1	155	0.2910	1	11	0.1464
	P4	2000	9" Ekman	65	2	177	0.2909	1	3	0.0316
	P4	2000	9" Ekman	65	3	133	0.2655	1	1	0.0006
	P4	2000	9" Ekman	65	4	183	0.2800	1	33	0.8046
	P4	2000	9" Ekman	65	5	200	0.3396	1	2	0.0058
	Lev-25	2001	9" Ekman	25	1	65	0.0625	1	33	1.1489
	Lev-25	2001	9" Ekman	25	2	129	0.1564	1	40	1.0014
	Lev-25	2001	9" Ekman	25	3	156	0.1517	1	82	1.8169
	Lev-25	2001	9" Ekman	25	4	122	0.0964	1	86	1.7614
	Lev-39	2001	9" Ekman	39	2	73	0.1358	1	0	0.0000
	Lev-39	2001	9" Ekman	39	3	82	0.0849	1	5	3.2140
	Lev-39	2001	9" Ekman	39	4	69	0.1188	1	1	0.6212
	Lev-39	2001	9" Ekman	39	5	148	0.3376	1	23	14.2865
	P3	2001	9" Ekman	44	1	223	1.6925	1	154	15.4532
	P3	2001	9" Ekman	44	2	168	0.2336	1	104	9.0331
	P3	2001	9" Ekman	44	3	226	0.2648	1	70	6.7723
	P3	2001	9" Ekman	44	4	133	0.1423	1	0	0.0000
	P4	2001	9" Ekman	65	1	157	0.1386	1	4	0.3382
	P4	2001	9" Ekman	65	2	160	0.1438	1	3	0.0069
	P4	2001	9" Ekman	65	3	252	0.1902	1	10	0.2555
	P4	2001	9" Ekman	65	4	145	0.2003	1	123	4.8220
	Meyers Pt.	2001	9" Ekman	99	1	44	0.9365	1	28	0.1693
	Meyers Pt.	2001	9" Ekman	99	2	2	0.4270	1	1	0.0119
	Meyers Pt.	2001	9" Ekman	99	3	10	0.2389	1	4	0.0234

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Appendix 14c. Continued. Finger Lakes (New York State).

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia*		Zebra Mussel		
						Density	Biomass	Presence	Density	Biomass
Seneca										
	P3	2002	9" Ekman	44	1	201	0.2496	1	28	1.66679
	P3	2002	9" Ekman	44	2	259	0.2518	1	129	9.07612
	P3	2002	9" Ekman	44	3	316	0.1917	1	28	2.42131
	P3	2002	9" Ekman	44	4	179	0.2421	1	22	1.57035
	P3	2002	9" Ekman	44	5	328	0.2508	1	85	7.76379
	P4	2002	9" Ekman	65	1	196	0.2043	1	26	0.75231
	P4	2002	9" Ekman	65	2	209	0.1817	1	34	0.83241
	P4	2002	9" Ekman	65	3	140	0.1650	1	139	5.01183
	P4	2002	9" Ekman	65	4	172	0.1542	1	22	0.94455
	P4	2002	9" Ekman	65	5	210	0.2424	1	13	0.14807
	30 m	1918	9" Ekman	30	Ave	55.5	0.2049	0	na	na
	45 m	1918	9" Ekman	45	Ave	42.2	0.1558	0	na	na
	110 m	1918	9" Ekman	110	Ave	17.8	0.0655	0	na	na
	172 m	1918	9" Ekman	172	Ave	6.7	0.0245	0	na	na
	30 m	2001	9" Ekman	30	2	96	0.0795	1	207	21.068
	30 m	2001	9" Ekman	30	3	49	0.0329	1	16	1.8852
	30 m	2001	9" Ekman	30	4	55	0.0275	1	24	2.7843
	30 m	2001	9" Ekman	30	5	56	0.0461	1	268	79.9143
	45 m	2001	9" Ekman	45	1	137	0.1743	1	2	0.2685
	45 m	2001	9" Ekman	45	2	199	0.1511	1	36	4.5560
	45 m	2001	9" Ekman	45	3	64	0.0821	1	139	21.790
	45 m	2001	9" Ekman	45	4	58	0.0502	1	3	0.1645
	110 m	2001	9" Ekman	110	1	59	0.7862	1	10	0.1445
	110 m	2001	9" Ekman	110	2	45	0.0543	1	0	0.0000
	110 m	2001	9" Ekman	110	3	56	0.0571	1	5	0.0118
	110 m	2001	9" Ekman	110	4	119	0.0979	1	15	0.2367

Appendix 14d. Northern lakes. *Diporeia* spp. density (no./sample), biomass (g/sample wet weight), and zebra mussels presence (1 = present, 0 = absent) for sample years 1959-2003, zebra mussel density (no./sample), biomass (g/sample wet weight), na = not available.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia*		Zebra Mussel		
						Density	Biomass	Presence	Density	Biomass
Batchawana Bay										
	K-7	1977	9" Ponar	20.5	1	8	0.0267	0		
	K-7	1977	9" Ponar	20.5	2	1	0.0076	0		
	K-7	1977	9" Ponar	20.5	3	4.5	0.0172	0		
	B (L-5)	1977	9" Ponar	32	1	30	0.0843	0		
	B (L-5)	1977	9" Ponar	32	2	11	0.0212	0		
	B (L-5)	1977	9" Ponar	32	3	38.94	0.0595	0		
	B (L-5)	1977	9" Ponar	32	4	6.3	0.0183	0		
	B (L-5)	1977	9" Ponar	32	5	26	0.0432	0		
	B (L-5)	1977	9" Ponar	32	6	31	0.0495	0		
	B (L-5)	1977	9" Ponar	32	7	25	0.0752	0		
	B (L-5)	1977	9" Ponar	32	8	24	0.0718	0		
	B (L-5)	1977	9" Ponar	32	9	56	0.1348	0		
	B (L-5)	1977	9" Ponar	32	10	46	0.1237	0		
	B (L-5)	1977	9" Ponar	32	11	45.7	0.1136	0		
	B (L-5)	1977	9" Ponar	32	12	41	0.0715	0		
	C (H-11)	1977	9" Ponar	46	1	42	0.0755	0		
	C (H-11)	1977	9" Ponar	46	2	24	0.0314	0		
	C (H-11)	1977	9" Ponar	46	3	33	0.0638	0		
	C (H-11)	1977	9" Ponar	46	4	6	0.0110	0		
	C (H-11)	1977	9" Ponar	46	5	69	0.1288	0		
	C (H-11)	1977	9" Ponar	46	6	45	0.0840	0		
	C (H-11)	1977	9" Ponar	46	7	43	0.1131	0		
	C (H-11)	1977	9" Ponar	46	8	54	0.0720	0		
	C (H-11)	1977	9" Ponar	46	9	38	0.0690	0		
	C (H-11)	1977	9" Ponar	46	10	59	0.1322	0		
	J-4	1978	9" Ponar	25	1	6	0.0180	0		
	J-4	1978	9" Ponar	25	2	10	0.0296	0		
	J-4	1978	9" Ponar	25	3	13	0.0240	0		
	J-4	1978	9" Ponar	25	4	9	0.0286	0		
	B (L-5)	1978	9" Ponar	32	1	36.3	0.0634	0		
	B (L-5)	1978	9" Ponar	32	2	37.9	0.0662	0		
	B (L-5)	1978	9" Ponar	32	3	33.7	0.0306	0		
	B (L-5)	1978	9" Ponar	32	4	29.5	0.0476	0		
	B (L-5)	1978	9" Ponar	32	5	16.8	0.0300	0		
	B (L-5)	1978	9" Ponar	32	6	14.7	0.0289	0		
	B (L-5)	1978	9" Ponar	32	7	12.5	0.0262	0		
	B (L-5)	1978	9" Ponar	32	8	17.2	0.0300	0		
	B (L-5)	1978	9" Ponar	32	9	14.6	0.0360	0		
	B (L-5)	1978	9" Ponar	32	10	23	0.0233	0		
	B (L-5)	1978	9" Ponar	32	11	37.9	0.0539	0		
	B (L-5)	1978	9" Ponar	32	12	26.4	0.0461	0		
	B (L-5)	1978	9" Ponar	32	13	27.4	0.0478	0		

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Appendix 14d. Continued. Northern lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence	Zebra Mussel Density	Zebra Mussel Biomass
Batchawana Bay										
	B (L-5)	1978	9" Ponar	32	14	19.05	0.0326	0		
	B (L-5)	1978	9" Ponar	32	15	27.3	0.0630	0		
	B (L-5)	1978	9" Ponar	32	17	17.79	0.0298	0		
	B (L-5)	1978	9" Ponar	32	18	24.2	0.0545	0		
	B (L-5)	1978	9" Ponar	32	19	31.6	0.0749	0		
	B (L-5)	1978	9" Ponar	32	21	27.26	0.0397	0		
	B (L-5)	1978	9" Ponar	32	22	14.2	0.0335	0		
	B (L-5)	1978	9" Ponar	32	23	11	0.0190	0		
	B (L-5)	1978	9" Ponar	32	24	7.8	0.0184	0		
	C (H-11)	1978	9" Ponar	46	1	34.28	0.0844	0		
	C (H-11)	1978	9" Ponar	46	2	15.98	0.0332	0		
	C (H-11)	1978	9" Ponar	46	3	18	0.0263	0		
	C (H-11)	1978	9" Ponar	46	4	27.85	0.0486	0		
	C (H-11)	1978	9" Ponar	46	5	25.64	0.0545	0		
	C (H-11)	1978	9" Ponar	46	6	31.51	0.0583	0		
	C (H-11)	1978	9" Ponar	46	7	32.88	0.0598	0		
	C (H-11)	1978	9" Ponar	46	8	36.98	0.0501	0		
	C (H-11)	1978	9" Ponar	46	8	35.81	0.0656	0		
	K-7	2001	9" Ekman	20.5	2	14	0.0268	0		
	K-7	2001	9" Ekman	20.5	4	7	0.0101	0		
	K-7	2001	9" Ekman	20.5	5	16	0.0438	0		
	J-4	2001	9" Ekman	25.1	1	12	0.0236	0		
	J-4	2001	9" Ekman	25.1	2	20	0.0242	0		
	J-4	2001	9" Ekman	25.1	3	29	0.0292	0		
	B (L-5)	2001	9" Ekman	32	2	38	0.0956	0		
	B (L-5)	2001	9" Ekman	32	3	47	0.1664	0		
	B (L-5)	2001	9" Ekman	32	4	37	0.0761	0		
	C (H-11)	2001	9" Ekman	46	2	27	0.0730	0		
	C (H-11)	2001	9" Ekman	46	4	34	0.0885	0		
	C (H-11)	2001	9" Ekman	46	5	23	0.0473	0		
Turkey										
	A	1980	9" Ekman	21.5	1	13	0.0037	0		
	A	1980	9" Ekman	21.5	2	26	0.0073	0		
	A	1980	9" Ekman	21.5	3	11	0.0021	0		
	A	1980	9" Ekman	21.5	4	9	0.0026	0		
	B	1980	9" Ekman	26.8	1	42	0.0016	0		
	B	1980	9" Ekman	26.8	2	3	0.0005	0		
	B	1980	9" Ekman	26.8	3	23	0.0010	0		
	C	1980	9" Ekman	35.0	1	0	0	0		
	C	1980	9" Ekman	35.0	1	0	0	0		
	A	2001	9" Ekman	21.5	1	43	0.0313	0		
	A	2001	9" Ekman	21.5	2	130	0.0761	0		
	A	2001	9" Ekman	21.5	3	9	0.0068	0		
	A	2001	9" Ekman	21.5	5	62	0.0800	0		

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Appendix 14d. Continued. Northern lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia*		Zebra Mussel		
						Density	Biomass	Presence	Density	Biomass
South Bay										
	B	2001	9" Ekman	26.8	1	89	0.0867	0		
	B	2001	9" Ekman	26.8	2	84	0.1199	0		
	B	2001	9" Ekman	26.8	3	84	0.0810	0		
	B	2001	9" Ekman	26.8	5	61	0.0743	0		
	C	2001	9" Ekman	35.0	1	0	0	0		
	C	2001	9" Ekman	35.0	4	0	0	0		
	C	2001	9" Ekman	35.0	5	0	0	0		
	6	1959	9" Ekman	14	1	19	na	0		
	6	1959	9" Ekman	14	2	28	na	0		
	6	1959	9" Ekman	14	3	18	na	0		
	5	1959	9" Ekman	13	6	45	na	0		
	5	1959	9" Ekman	13	7	47	na	0		
	5	1959	9" Ekman	13	8	52	na	0		
	5	1959	9" Ekman	13	9	62	na	0		
	5	1959	9" Ekman	13	10	38	na	0		
	5	1959	9" Ekman	13	11	54	na	0		
	5	1959	9" Ekman	13	12	43	na	0		
	5	1959	9" Ekman	13	13	53	na	0		
	5	1959	9" Ekman	13	14	54	na	0		
	5	1959	9" Ekman	13	15	26	na	0		
	5	1959	9" Ekman	13	16	41	na	0		
	5	1959	9" Ekman	13	17	56	na	0		
	5	1959	9" Ekman	13	18	48	na	0		
	5	1959	9" Ekman	13	19	43	na	0		
	7	1959	9" Ekman	20	1	7	na	0		
	7	1959	9" Ekman	20	2	15	na	0		
	7	1959	9" Ekman	20	3	17	na	0		
	7	1959	9" Ekman	20	4	19	na	0		
	7	1959	9" Ekman	20	5	39	na	0		
	7	1959	9" Ekman	20	6	61	na	0		
	7	1959	9" Ekman	20	7	49	na	0		
	7	1959	9" Ekman	20	8	56	na	0		
	8	1959	9" Ekman	36	1	15	na	0		
	8	1959	9" Ekman	36	2	24	na	0		
	8	1959	9" Ekman	36	3	14	na	0		
	8	1959	9" Ekman	36	4	20	na	0		
	8	1959	9" Ekman	36	5	108	na	0		
	8	1959	9" Ekman	36	6	247	na	0		
	8	1959	9" Ekman	36	7	223	na	0		
	8	1959	9" Ekman	36	8	230	na	0		
	8	1959	9" Ekman	36	9	260	na	0		
	8	1959	9" Ekman	36	10	116	na	0		
	8	1959	9" Ekman	36	11	105	na	0		
	8	1959	9" Ekman	36	12	169	na	0		
	8	1959	9" Ekman	36	13	126	na	0		

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Appendix 14d. Continued. Northern Lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence	Zebra Mussel Density	Zebra Mussel Biomass
South Bay										
	9	1959	9" Ekman	55	1	12	na	0		
	9	1959	9" Ekman	55	2	1	na	0		
	9	1959	9" Ekman	55	3	11	na	0		
	9	1959	9" Ekman	55	4	21	na	0		
	9	1959	9" Ekman	55	5	10	na	0		
	9	1959	9" Ekman	55	6	15	na	0		
	9	1959	9" Ekman	55	7	1	na	0		
	9	1959	9" Ekman	55	8	4	na	0		
	9	1959	9" Ekman	55	9	172	na	0		
	9	1959	9" Ekman	55	10	137	na	0		
	9	1959	9" Ekman	55	11	70	na	0		
	9	1959	9" Ekman	55	12	209	na	0		
	6	1981	9" Ekman	12	1	0	na	0		
	6	1981	9" Ekman	13	1	4	na	0		
	6	1981	9" Ekman	13	1	8	na	0		
	7	1981	9" Ekman	21	1	5	na	0		
	7	1981	9" Ekman	19	1	0	na	0		
	7	1981	9" Ekman	19	1	7	na	0		
	8	1981	9" Ekman	36	1	23.7	na	0		
	8	1981	9" Ekman	36	2	32.7	na	0		
	8	1981	9" Ekman	36	3	28.2	na	0		
	9	1981	9" Ekman	55	1	116.5	na	0		
	9	1981	9" Ekman	55	2	197.3	na	0		
	9	1981	9" Ekman	55	3	174.1	na	0		
	6	2001	9" Ekman	14	1	2	0.0005	0		
	6	2001	9" Ekman	14	2	5	0.0035	0		
	6	2001	9" Ekman	14	3	9	0.0051	0		
	6	2001	9" Ekman	14	4	3	0.0018	0		
	6	2001	9" Ekman	14	5	1	0.0005	0		
	7	2001	9" Ekman	20	1	11	0.0041	1	74	41.934
	7	2001	9" Ekman	20	2	5	0.0025	1	32	18.023
	7	2001	9" Ekman	20	3	1	0.0044	1	40	26.205
	7	2001	9" Ekman	20	4	1	0.0005	1	72	29.333
	7	2001	9" Ekman	20	5	2	0.0013	1	84	62.608
	8	2001	9" Ekman	36	1	17	0.0386	0		
	8	2001	9" Ekman	36	2	6	0.0152	0		
	8	2001	9" Ekman	36	3	19	0.0444	0		
	8	2001	9" Ekman	36	4	28	0.0655	0		
	14	2001	9" Ekman	32	1	0	0	0		
	14	2001	9" Ekman	32	2	7	0.0041	0		
	14	2001	9" Ekman	32	3	4	0.0010	1	2	1.3443
	14	2001	9" Ekman	32	4	0	0	0		
	14	2001	9" Ekman	32	5	7	0.0039	0		
	25	2001	9" Ekman	37	1	23	0.0193	0		
	25	2001	9" Ekman	37	2	12	0.0215	1	1	0.0001

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Appendix 14d. Continued. Northern lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence	Zebra Mussel Density	Zebra Mussel Biomass
South Bay										
	25	2001	9" Ekman	37	3	16	0.0380	0		
	25	2001	9" Ekman	37	4	33	0.0338	0		
	25	2001	9" Ekman	37	5	32	0.0520	0		
	18	2001	9" Ekman	45	1	20	0.0555	0		
	18	2001	9" Ekman	45	2	24	0.0402	0		
	18	2001	9" Ekman	45	3	15	0.0311	0		
	18	2001	9" Ekman	45	4	18	0.0361	0		
	18	2001	9" Ekman	45	5	17	0.0257	0		
	9	2001	9" Ekman	55	1	27	0.0378	0		
	9	2001	9" Ekman	55	2	7	0.0258	0		
	9	2001	9" Ekman	55	3	29	0.0689	0		
	9	2001	9" Ekman	55	4	20	0.0418	0		
	7	2002	9" Ekman	20	1	1	0.0018	1	1	0.9260
	7	2002	9" Ekman	20	2	1	0.0029	1	177	160.49
	7	2002	9" Ekman	20	3	0	0	1	131	100.69
	7	2002	9" Ekman	20	4	1	0.0008	1	146	104.39
	8	2002	9" Ekman	35	1	11	0.0418	0		
	8	2002	9" Ekman	35	2	16	0.0463	0		
	8	2002	9" Ekman	35	3	12	0.0270	0		
	8	2002	9" Ekman	35	4	11	0.0311	0		
	14	2002	9" Ekman	34	1	1	0.0007	0		
	14	2002	9" Ekman	34	2	5	0.0075	0		
	14	2002	9" Ekman	34	3	0	0	1	10	7.2890
	14	2002	9" Ekman	34	4	0	0	0		
	25	2002	9" Ekman	37	1	11	0.0220	0		
	25	2002	9" Ekman	37	2	20	0.0484	0		
	25	2002	9" Ekman	37	3	10	0.0258	0		
	25	2002	9" Ekman	37	4	9	0.0223	0		
	18	2002	9" Ekman	45	1	9	0.0173	0		
	18	2002	9" Ekman	45	2	15	0.0366	0		
	18	2002	9" Ekman	45	3	7	0.0193	0		
	18	2002	9" Ekman	45	4	24	0.0449	0		
	9	2002	9" Ekman	55	1	19	0.0321	0		
	9	2002	9" Ekman	55	2	8	0.0247	0		
	9	2002	9" Ekman	55	3	4	0.0026	0		
	9	2002	9" Ekman	55	4	17	0.0390	0		
	6	2003	9" Ekman	14.4	1	6	0.0150	0		
	6	2003	9" Ekman	14.4	2	5	0.0082	1	3	2.4237
	6	2003	9" Ekman	14.4	3	7	0.0101	0		
	7	2003	9" Ekman	20.0	1	0	0	1	3	0.9008
	7	2003	9" Ekman	20.0	2	5	0.0108	1	23	18.059
	7	2003	9" Ekman	20.0	3	0	0	1	7	4.5527
	14	2003	9" Ekman	30.6	1	23	0.0193	1	1	0.0021
	14	2003	9" Ekman	30.6	2	27	0.0245	0		
	14	2003	9" Ekman	30.6	3	24	0.0261	0		

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Appendix 14d. Continued. Northern lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence	Zebra Mussel Density	Zebra Mussel Biomass
South Bay										
	8	2003	9" Ekman	34.7	1	12	0.0106	0		
	8	2003	9" Ekman	34.7	2	13	0.0192	0		
	8	2003	9" Ekman	34.7	3	18	0.0322	0		
	25	2003	9" Ekman	36.7	1	9	0.0086	0		
	25	2003	9" Ekman	36.7	2	10	0.0273	0		
	25	2003	9" Ekman	36.7	3	5	0.0081	0		
	18	2003	9" Ekman	44.2	1	12	0.0093	0		
	18	2003	9" Ekman	44.2	2	14	0.0259	0		
	18	2003	9" Ekman	44.2	3	10	0.0232	0		
	9	2003	9" Ekman	55.0	1	2	0.0084	0		
	9	2003	9" Ekman	55.0	2	5	0.0201	0		
	9	2003	9" Ekman	55.5	3	11	0.0323	0		
	14	2003	9" Ekman	34	Ave	16	na	na		
	28	2003	9" Ekman	36	Ave	16	na	na		
	22	2003	9" Ekman	43	Ave	3	na	na		
	25	2003	9" Ekman	45	Ave	7	na	na		
	18	2003	9" Ekman	46	Ave	6	na	na		
Winnipeg										
	27	1969	6" Ekman	7.3	1	69.34	na	0		
	27	1969	6" Ekman	7.3	2	103	na	0		
	27	1969	6" Ekman	7.3	3	120.9	na	0		
	27	1969	6" Ekman	7.3	4	65.65	na	0		
	5	1969	6" Ekman	9.8	1	1	na	0		
	5	1969	6" Ekman	9.8	2	0	na	0		
	5	1969	6" Ekman	9.8	3	0	na	0		
	5	1969	6" Ekman	9.8	4	0	na	0		
	5	1969	6" Ekman	9.8	1	0.34	na	0		
	12B	1969	6" Ekman	11.0	2	11.1	na	0		
	12B	1969	6" Ekman	11.0	3	0	na	0		
	12B	1969	6" Ekman	11.0	4	0	na	0		
	54	1969	6" Ekman	12.5	1	119.86	na	0		
	54	1969	6" Ekman	12.5	2	204.7	na	0		
	54	1969	6" Ekman	12.5	3	170.02	na	0		
	54	1969	6" Ekman	12.5	4	154.52	na	0		
	54	1969	6" Ekman	12.5	5	138.02	na	0		
	17	1969	6" Ekman	15.0	1	127	na	0		
	17	1969	6" Ekman	15.0	2	106.4	na	0		
	17	1969	6" Ekman	15.0	3	194.25	na	0		
	26	1969	6" Ekman	15.0	1	0	na	0		
	26	1969	6" Ekman	15.0	2	0	na	0		
	26	1969	6" Ekman	15.0	3	0.68	na	0		
	26	1969	6" Ekman	15.0	4	0	na	0		
	26	1969	6" Ekman	15.0	5	0	na	0		

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Appendix 14d. Continued. Northern lakes.

Lake	Site	Year	Sampler	Depth (m)	Rep. no.	*Diporeia* Density	*Diporeia* Biomass	Zebra Mussel Presence	Zebra Mussel Density	Zebra Mussel Biomass
Winnipeg										
	20S	1969	6" Ekman	16.2	1	30.79	na	0		
	20S	1969	6" Ekman	16.2	2	173.72	na	0		
	20S	1969	6" Ekman	16.2	3	24.48	na	0		
	23C	1969	6" Ekman	16.4	1	0	na	0		
	23C	1969	6" Ekman	16.4	2	0	na	0		
	23C	1969	6" Ekman	16.4	3	1.68	na	0		
	23C	1969	6" Ekman	16.4	4	0	na	0		
	23C	1969	6" Ekman	16.4	5	0.68	na	0		
	23E	1969	6" Ekman	17.4	4	0	na	0		
	23E	1969	6" Ekman	17.4	5	0	na	0		
	23E	1969	6" Ekman	17.4	6	0	na	0		
	23E	1969	6" Ekman	17.4	7	0.34	na	0		
	23E	1969	6" Ekman	17.4	8	1	na	0		
	60B	2002	6" Ekman	7.5	1	5	na	0		
	60B	2002	6" Ekman	7.5	2	3	na	0		
	60B	2002	6" Ekman	7.5	3	6	na	0		
	5	2002	6" Ekman	9.8	1	22	na	0		
	5	2002	6" Ekman	9.8	2	7	na	0		
	5	2002	6" Ekman	9.8	3	18	na	0		
	59	2002	6" Ekman	10.3	1	0	na	0		
	59	2002	6" Ekman	10.3	2	0	na	0		
	59	2002	6" Ekman	10.3	3	0	na	0		
	12B	2002	6" Ekman	11	1	1	na	0		
	12B	2002	6" Ekman	11	2	5	na	0		
	12B	2002	6" Ekman	11	3	6	na	0		
	54	2002	6" Ekman	12.5	1	204	na	0		
	54	2002	6" Ekman	12.5	2	154	na	0		
	54	2002	6" Ekman	12.5	3	316.4	na	0		
	54	2002	6" Ekman	12.5	1	119.86	na	0		
	54	2002	6" Ekman	12.5	2	204.7	na	0		
	54	2002	6" Ekman	12.5	3	170.02	na	0		
	54	2002	6" Ekman	12.5	4	154.52	na	0		
	54	2002	6" Ekman	12.5	5	138.02	na	0		
	26S	2002	6" Ekman	15.2	1	0	na	0		
	26S	2002	6" Ekman	15.2	2	0	na	0		
	26S	2002	6" Ekman	15.2	3	0	na	0		
	17	2002	6" Ekman	15.5	1	0	na	0		
	17	2002	6" Ekman	15.5	2	0	na	0		
	17	2002	6" Ekman	15.5	3	0	na	0		
	20S	2002	6" Ekman	17.5	1	47	na	0		
	20S	2002	6" Ekman	17.5	2	26	na	0		
	20S	2002	6" Ekman	17.5	3	40	na	0		

Appendix 15. Average *Diporeia* density (no./9" Ekman) for all sampled lakes in pre and post zebra mussels time periods.

Lake	Pre Zebra Mussels			Post Zebra Mussel		
	Sample Size	Average Density	Standard Error	Sample Size	Average Density	Standard Error
Lakes without zebra mussels						
Turkey	9	14.10	4.637	11	51.10	13.388
Mazinaw	6	19.70	1.783	23	13.90	2.205
Memphrémagog	27	22.62	6.7725	21	21.29	4.1968
Bernard	8	24.40	7.405	19	82.00	12.00
Round	8	28.10	4.077	15	5.500	1.323
Batchawana Bay	56	28.12	1.939	12	25.33	3.504
George	9	31.61	6.21	15	87.94	16.06
Winnipeg	49	81.51	34.39	24	83.27	39.05
Blue Sea	8	156.80	15.874	15	226.30	23.77
Charleston	5	196.00	28.836	15	194.90	49.441
Lakes with zebra mussels						
Champlain	25	5.00	4.75	32	0.00	0.00
Seneca	4	30.50	11.155	12	82.80	13.551
South Bay	56	69.30	9.411	57	11.10	1.218
Cayuga	12	136.30	35.887	26	155.10	9.363